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WEATHER EXTREMES AROUND THE WORLD

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Fort Belvoir, Virginia

April 1974

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Extremes	Precipitation (meteorology)	Humidity
Weather	Atmospheric pressure	Fog
Weather observations	Solar radiation	Thunderstorms
Meteorological charts	Wind (meteorology)	
Temperature	Weather intelligence	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report consists of a worldwide map of weather extremes and a separate map for North America, with comments on the reliability of the records shown. Included are highest and lowest temperatures, largest temperature variations, greatest and least amounts of precipitation for various durations, maximum precipitation variability, greatest thunderstorm frequency, highest and lowest atmospheric pressure, highest solar radiation largest hailstones, greatest snowfall, highest wind speed, high dew point, and most frequent occurrence of dense fog.

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Where appropriate, the value for the highest and lowest annual mean is also given. As far as possible, the records are taken from official sources, and all of them are documented. Conditions of site, instrumentation, observational procedure, and other factors such as environmental and meteorological conditions pertinent to the reliability of extremes are discussed.

PREFACE

In 1955, a map titled "World Weather Extremes" was prepared by the Cartography Branch of the Environmental Protection Research Division, Quartermaster Research and Engineering Center, Natick, Massachusetts, for distribution to visitors and other interested persons. This map showed the location of certain meteorological extremes which had been recorded in climatological publications. In subsequent years the map was periodically revised as new records came to light and the number of requests for it increased. It has been reprinted in a number of publications, both military and civilian, and has been widely used for instruction and display purposes.

In 1969, a need for an updated map and some discussion of the records shown appeared in the Earth Sciences Laboratory at Natick in connection with a revision of Military Standard 210A, "Climatic Extremes for Military Equipment." Natick Laboratories had been assigned responsibility for certain portions of the standard. As an indication of the most extreme climatic conditions that have been recorded in various parts of the earth, the map gives an approximation of the absolute limits within which design criteria must be established.

In addition to the revised map of world weather extremes, a new map showing extremes in North America was added and the sources for records on both maps were reviewed and documented. When controversial records were included, the arguments for and against their acceptance were examined and summarized in the text. For many of the records, the text included such information as the conditions during occurrence of the extremes, problems of measuring or recording them, and the kinds of investigations carried out by the U. S. Weather Bureau before they were accepted. Thus, for the first time a map of extreme weather occurrences was presented together with full documentation of the sources of the records and references to pertinent comments in the technical literature.

Weather records continue to be broken and the maps and text again have been updated. In addition, some further background material has been included and some changes have been made to improve textual clarity. This work has been carried out in the Environmental Criteria Branch of the Engineer Topographic Laboratories at Fort Belvoir, Virginia, which is the successor organization to the former Earth Sciences Laboratory at Natick.

Valuable advice and information were received from Dr. M. A. Arkin, Environmental Data Service, National Oceanic and Atmospheric Administration (NOAA) for both this revision and the original report. His assistance is acknowledged with appreciation. The cartography in the original report was completed by Ms Kristin Gill and Ms Olive Lesueur,

under the direction of Aubrey Greenwald, Jr., Chief of the Cartography Office, Earth Sciences Laboratory. It has been reproduced, with the necessary updating for this report, by SP-4 Richard Vail under the direction of James Smith of the Topographic Products Development Branch of Engineer Topographic Laboratories. Their assistance and suggestions are appreciated as are the suggestions made for printing the records by categories on the reverse of the map sheets by Dr. William Robison and for setting up coordinates for locating the places of occurrence of the records on the world map by Ms Jane Kroll, both of the Engineer Topographic Laboratories.

CONTENTS

WEATHER EXTREMES AROUND THE WORLD

I. INTRODUCTION

1. **Subject.** The world map and the map of North America were prepared primarily as aids in specifying extreme climatic conditions for design of military equipment. The two maps together contain approximately 100 records. The categories of extremes indicated in MIL-STD 210A were kept in mind in the selection of records, but selection was not limited to these categories. This report is primarily intended to review the validity of the records. A listing of the records, with documentation of their sources, is followed by a commentary on their reliability.

The representativeness and significance of weather records in general are commented upon, and for each of the main elements, certain factors bearing on reliability are noted. Among these are measuring instruments and problems, environmental conditions which favor occurrence of extremes, theoretical limits of occurrence, and the geographical areas and seasons in which the probability of extremes is greatest. Following this general treatment, pertinent information is given about individual records and their documentation. There is much information available about some of the extremes, especially controversial ones, but little or nothing about others. Similarly, records are more easily available to us for the United States and Canada than for other countries. To make room for showing these records, and because Americans would be especially interested in records of their own continent, the North America map has been included.

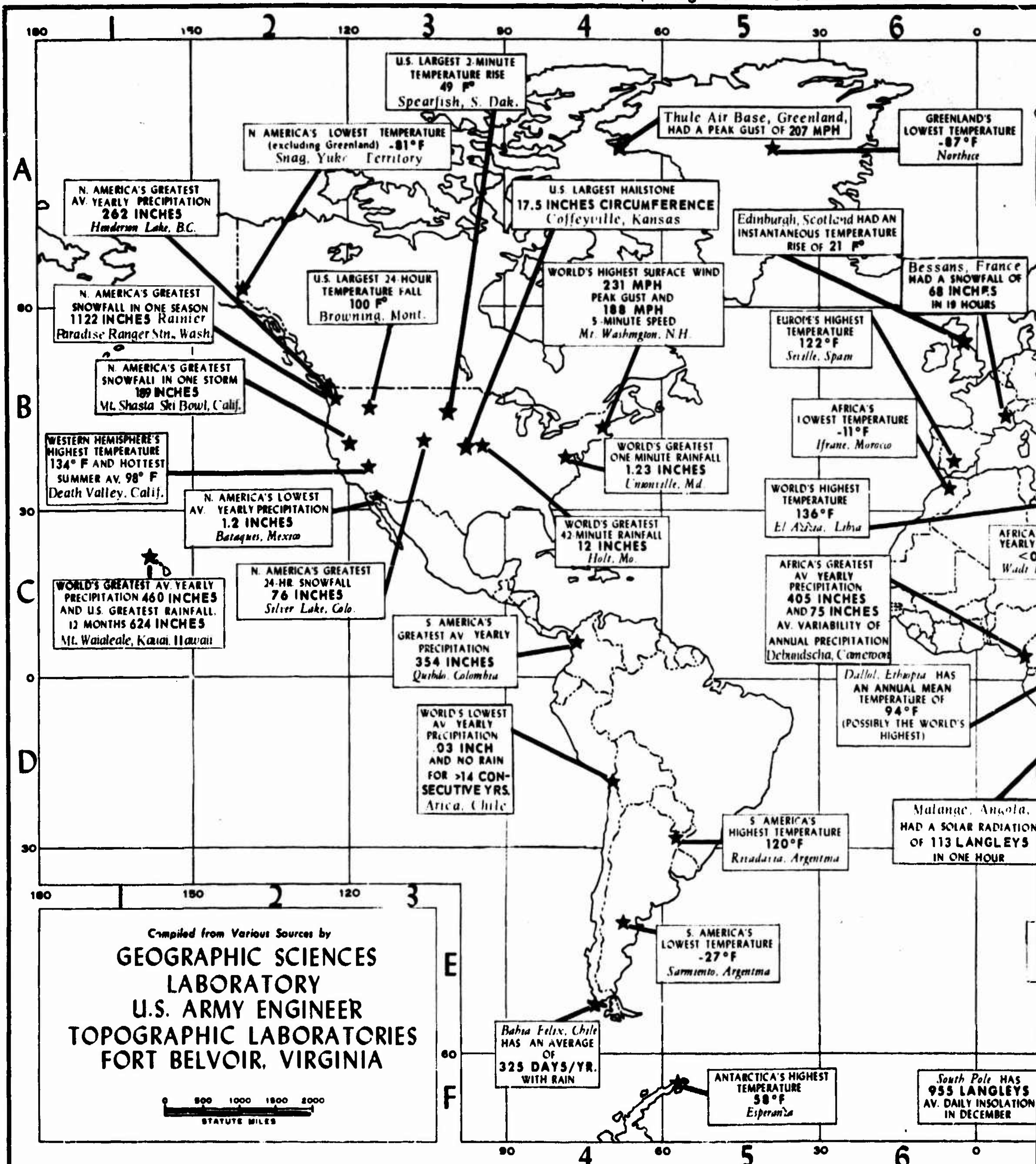
In addition to documenting each of the records, we have coordinated them, where possible, with determinations of the Environmental Data Service (EDS) part of the U.S. NOAA. In the United States, EDS is responsible for archiving and disseminating weather data, and in line with these functions it validates extreme occurrences, both at home and abroad.[1] Other countries follow a similar policy, but there is, as yet, no world agency that determines and establishes a register of weather extremes. As a result, a given record might be accepted by EDS but not by its equivalent agency in some other country.

2. **Documentation.** To facilitate finding the extremes for a particular element, the records are listed, with documentation, by elements (see the Table, pages 7-15). Records for each element are arranged in order of decreasing extremity beginning with the world's record if accepted as such.

[1] M. A. Arkin, Chief, Foreign Branch, Environmental Data Service, U. S. Environmental Science Services Administration, letter dated 10 Sep 69.

WEATHER EXTREMES AR

(Categories and co-ordinates of extremes a



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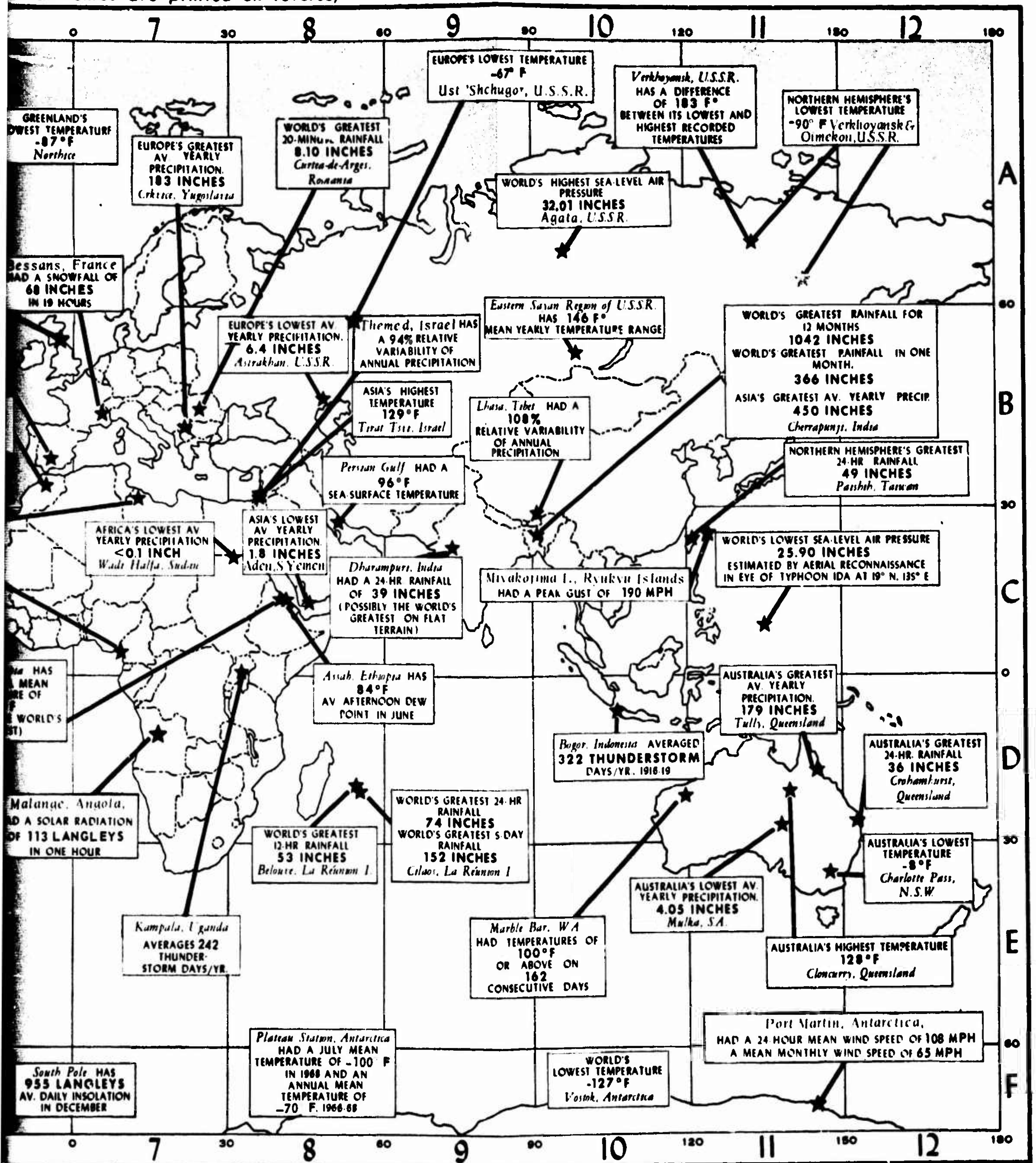

LOCATION OF WEATHER EXTREMES BY ELEMENT – WORLD MAP

I. TEMPERATURE

A. High

World: El Azizia, Libya B7
W. Hemisphere: Death Valley, California B3
Asia: Tirat Tsvi, Israel B8
Australia: Cloncurry, Queensland D11
Europe: Seville, Spain B6
S. America: Rivadavia, Argentina D5
Antarctica: Esperanza, Antarctic Peninsula F5
Sea surface: Persian Gulf C8
Annual mean: Dallol, Ethiopia C8
Hottest summers in W. Hemisphere: Death Valley, California B3
Long hot spell: Marble Bar, W. Australia D10

B. Low

World: Vostok, Antarctica F10
N. Hemisphere: Verkhoyansk & Oimekon, U.S.S.R. A11
Greenland: Northice A5
N. America (excluding Greenland): Snag, Yukon Territory A2
Europe: Ust 'Shchugor, U.S.S.R. B8
S. America: Sarmiento, Argentina E4
Africa: Ifrane, Morocco B6
Australia: Charlotte Pass, New South Wales E11
Monthly and annual means: Plateau Station, Antarctica F8

C. Variations

Difference between high and low: Verkhoyansk, U.S.S.R. A11
Mean annual range: Eastern Sayan Region of U.S.S.R. B10
Largest 2-minute rise in U.S.: Spearfish, South Dakota B3
Instantaneous rise: Edinburgh, Scotland B6
Largest 24-hour fall in U.S.: Browning, Montana B3

II. PRECIPITATION

A. Great Rainfall Amounts

One-minute, World: Unionville, Maryland B4
20-minute, World: Curtea-de-Arges, Romania B7
42-minute, World: Holt, Missouri B3
12-hour, World: Belouve, La Réunion I. D8
24-hour, World: Cilaos, La Réunion I. D8
24-hour, N. Hemisphere: Paishih, Taiwan C11
24-hour: Dharampuri, India C9
24-hour, Australia: Crohamhurst, Queensland D12
5-day, World: Cilaos, La Réunion I. D8
One month, World: Cherrapunji, India C10
12-months, World: Cherrapunji, India C10
12-months, U.S.: Mt. Waialeale, Kauai, Hawaii C1

B. Great Average Yearly Precipitation

World: Mt. Waialeale, Kauai, Hawaii C1
Asia: Cherrapunji, India C10
Africa: Debundscha, Cameroon C7
S. America: Quibdo, Colombia C4
N. America: Henderson Lake, British Columbia B2
Europe: Crkvice, Yugoslavia B7
Australia: Tully, Queensland D11
Average number of days with rain per year: Bahia Felix, Chile E4

C. Least Precip

Number

D. Low Average

World:
Africa:
N. Ame
Asia:
Austra
Europe

E. Variability o

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F. Hailstones

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G. Great Snowf

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III. OTHER ELEMENT

A. Thunderstorn

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B. Sea-Level

Highe
Lowe

C. Solar Radia

Avera
One-l

D. Wind Speed

Peak
Peak
Peak
5-mi
24-h
Mean
Days

E. Dew Point

Mean

C. Least Precipitation

Number of years without rain: Arica, Chile D4

D. Low Average Yearly Precipitation

World: Arica, Chile D4
Africa: Wadi Halfa, Sudan C8
N. America: Bataques, Mexico B3
Asia: Aden, South Yemen C8
Australia: Mulka, South Australia D11
Europe: Astrakhan, U.S.S.R. B8

E. Variability of Precipitation

Average variability: Debundscha, Cameroon C7
Relative variability: Themed, Israel B8
Relative variability (1935–38): Lhasa, Tibet C10

F. Hailstones

Largest, U.S.: Coffeyville, Kansas B3

G. Great Snowfall Amounts

24-hour, N. America: Silver Lake, Colorado B3
19-hour: Bessans, France B7
One storm, N. America: Mt. Shasta Ski Bowl, California B2
One season, N. America: Rainier Paradise Ranger Station, Washington B2

III. OTHER ELEMENTS

A. Thunderstorms

Average number of thunderstorm days per year: Kampala, Uganda C8
Average number of thunderstorm days, 1916–1919: Bogor, Indonesia D10

B. Sea-Level Air Pressure

Highest, World: Agata, U.S.S.R. A10
Lowest, World: estimated at 19° N, 135° E, C11

C. Solar Radiation

Average daily December: South Pole, Antarctica F6 & 7
One-hour: Malange, Angola D7

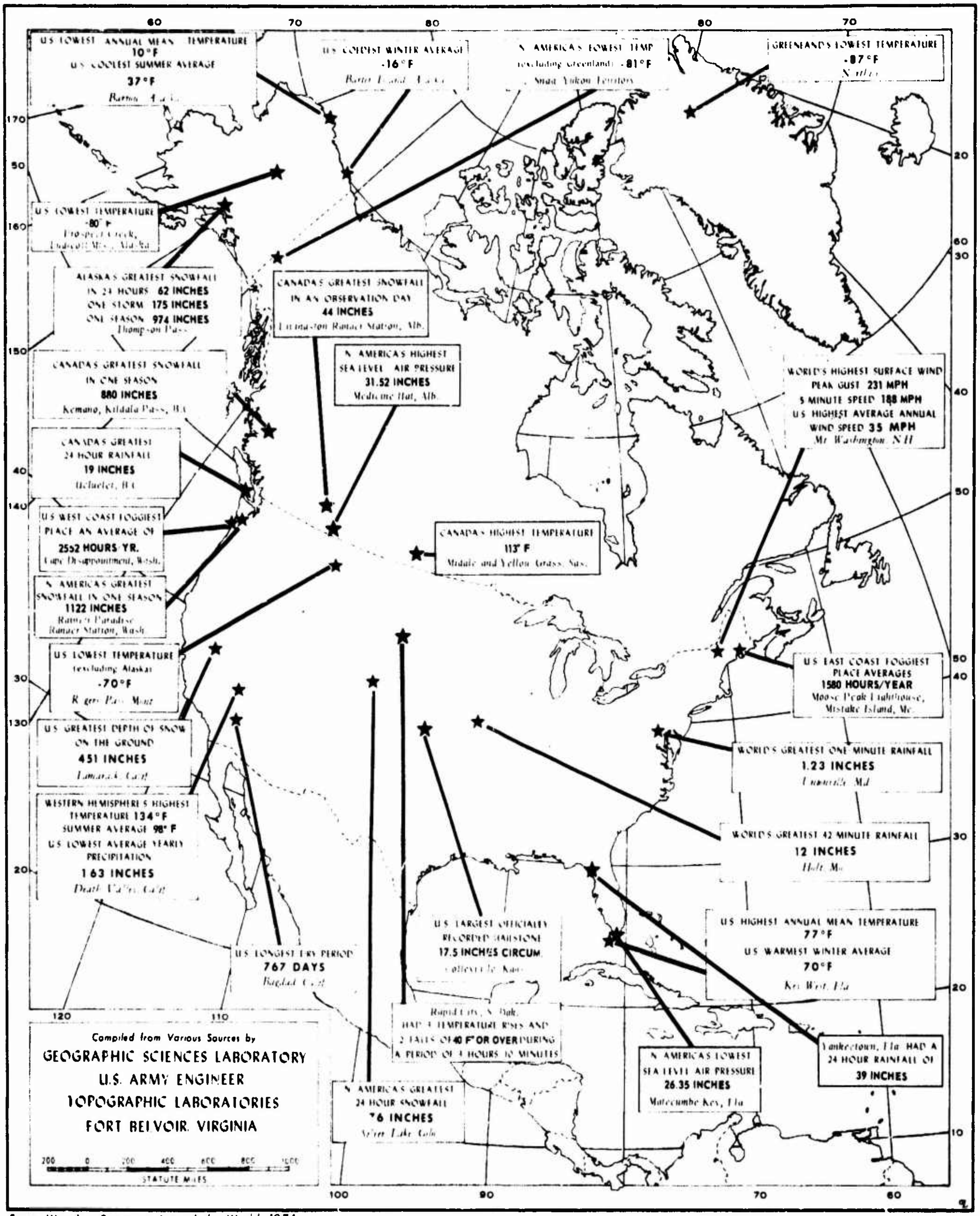
D. Wind Speed

Peak gust, World: Mt. Washington, New Hampshire B4
Peak gust, Thule Air Base, Greenland A4
Peak gust, Miyakojima I., Ryukyu Islands C11
5-minute, World: Mt. Washington, New Hampshire B4
24-hour mean: Port Martin, Antarctica F11
Mean monthly: Port Martin, Antarctica F11
Days with hurricane force winds: Port Martin, Antarctica F11

E. Dew Point

Mean afternoon, in June: Assab, Ethiopia C8

WEATHER EXTREMES IN NORTH AMERICA



From Weather Extremes Around the World, 1974

Weather Records – With Documentation by Element

Element (to nearest whole number)	Reference
I. Temperature	
A. <u>Highest</u>	
World, <u>136°F</u>, El Azizia, Libya, 13 September 1922	U.S. Environmental Science Services Administration, Environmental Data Service, *Temperature Extremes*, revised May 1967. (L.S. 5821.)
Western Hemisphere, <u>134°F</u>, Death Valley, California, 10 July 1913	*Ibid.*
Asia, <u>129°F</u>, Tirat Tsvi, Israel, 21 June 1942	U.S. Environmental Science Services Administration, Environmental Data Service. *Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area*, October 1968. (ESSA/PI680032.)
Australia, <u>128°F</u>, Cloncurry, Queensland, 16 January 1889	*Ibid.*
Europe, <u>122°F</u>, Seville, Spain, 4 August 1881	*Ibid.*
South America, <u>120°F</u>, Rivadavia, Argentina, 11 December 1905	*Ibid.*
Antarctica, <u>58°F</u>, Esperanza, Antarctic Peninsula, 20 October 1956	*Ibid.*
Canada, <u>113°F</u>, Midale and Yellow Grass, Saskatchewan, 5 July 1937	D. M. Ludlum, *Weather Record Book, U.S. and Canada*, Weatherwise, Princeton, New Jersey, 1971.
Persian Gulf had a <u>96°F</u> sea surface, 5 August 1924	U.S. Environmental Science Services Administration, Environmental Data Service, *Temperature Extremes*, revised May 1967. (L.S. 5821.)
Dallol, Ethiopia, has a <u>94°F</u> annual mean (possibly the world's highest)	D. E. Pedgley, *Air Temperatures at Dallol, Ethiopia*, *Meteorol. Mag.*, London, Vol. 96, No. 1142, pp. 265-71, 1967.
U.S. highest annual mean, <u>77°F</u>, Key West, Florida	M. A. Arkin, Chief, Foreign Branch, Environmental Data Service, U.S. Environmental Science Services Administration, correspondence dated 6 October 1969.

Weather Records – With Documentation by Element (Cont'd)

Element (to nearest whole number)	Reference
U.S. warmest winters, 70°F, average, Key West, Florida	U.S. Environmental Science Services Administration, Environmental Data Service, *Temperature Extremes*, revised May 1967. (L.S. 5821.)
Western Hemisphere hottest summers, 98°F, average, Death Valley, California	*Ibid.*
Marble Bar, West Australia, recorded temperatures of 100°F or above on 162 consecutive days, 30 October 1923 to 7 April 1924	H. T. Ashton and J. V. Maher, *Australian Forecasting and Climate*, 6th ed. Melbourne, Australia, 1960.
B. Lowest	
World, -127°F, Vostok, Antarctica, 24 August 1960	U.S. Environmental Science Services Administration, Environmental Data Service, *Temperature Extremes*, revised May 1967. (L.S. 5821.)
Northern Hemisphere, -90°F, Verkhoyansk, U.S.S.R., 5 and 7 February 1892; and Oimekon, U.S.S.R., 6 February 1933	*Ibid.*
Greenland, -87°F, Northice, 9 January 1954	*Ibid.*
North America, excluding Greenland, -81°F, Snag, Yukon Territory, 3 February 1947	*Ibid.*
U.S., -80°F, Prospect Creek, Alaska, 23 January 1971	D. M. Ludlum, *op. cit.*
U.S., excluding Alaska, -70°F, Rogers Pass, Montana, 20 January 1954	U.S. Environmental Science Services Administration, Environmental Data Service, *Temperature Extremes*, revised May 1967. (L.S. 5821.)
Europe, -67°F, Ust 'Shchugor, U.S.S.R. Jan (date not known)	U.S. Environmental Science Services Administration, Environmental Data Service, *Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area.* October 1968 (ESSA/ PI680032).
South America, -27°F, Sarmiento, Argentina, 1 June 1907	*Ibid.*
Africa, -11°F, Ifrane, Morocco, 11 February 1935	*Ibid.*

Weather Records – With Documentation by Element (Cont'd)

Element (to nearest whole number)	Reference
Australia, -8°F, Charlotte Pass, New South Wales, 14 June 1945 and 22 July 1947	*Ibid.*
Plateau Station, Antarctica, had a monthly mean of -100°F, July 1968, and an annual mean of -70°F, 1966-68	P. C. Dalrymple, Geographic Applications Division, U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Va., Personal Communication.
U.S. lowest annual mean, 10°F, Barrow, Alaska	U.S. Environmental Science Services Administration, Environmental Data Service, *Temperature Extremes*, revised May 1967. (L.S. 5821.)
U.S. coolest summers, 37°F average, Barrow, Alaska	*Ibid.*
U.S. coldest winters, -16°F average, Barter Island, Alaska	*Ibid.*
C. Temperature Variations	
Verkhoyansk, U.S.S.R. has a difference of 183F° (93.5 to -89.7) between highest and lowest recorded temperatures	S. P. Suslov, Physical Geography of Asiatic Russia, transl. by N. D. Gershevsky and ed. by J. E. Williams, W. H. Freeman, San Francisco, 1961.
Eastern Sayan Region of U.S.S.R. has a 146F° (93.2 to -53.2) annual mean temperature range	*Ibid.*
U.S. largest 2-minute temperature rise, 49F° (-4 to 45), Spearfish, South Dakota, 22 January 1943	R. R. Hamann, The Remarkable Temperature Fluctuations in the Black Hills Region, January 1943. *Monthly Weather Rev*, Vol., 71, No. 3, pp. 29-32, March 1943.
Edinburgh, Scotland, had an instantaneous temperature rise, 21F° (45 to 66), 8 April 1969	I. H. Chuter, A Sudden Rise of Temperature at Edinburgh, *Weather*, Vol. 21, No. 11, pp. 159-62, 1970.
U.S. largest 24-hour temperature fall, 100F° (44 to -56), Browning, Montana, 23-24 January 1916	U.S. Environmental Science Services Administration, Environmental Data Service, *Temperature Extremes*, revised May 1967. (L.S. 5821.)
Rapid City, South Dakota, had three temperature rises and two falls of 40F° or over during a period of 3 hours, 10 minutes, 22 January 1943	R. R. Hamann, *op. cit.*

Weather Records – With Documentation by Element (cont'd)

Element (to nearest whole number)	Reference
II. Precipitation	
A. Greatest Rainfall	
World, 1-minute, 1.23 inches, Unionville, Maryland, 4 July 1956	J. L. H. Paulhus. Indian Ocean and Taiwan Rainfalls Set New Records, *Monthly Weather Rev*, Vol. 93, No. 5, pp. 331-35, 1965.
World, 20-minute 8.10 inches, Curtea-de-Arges, Romania, 7 July 1889	*Ibid.*
World, 42-minute, 12 inches, Holt, Missouri, 22 June 1947	*Ibid.*
World, 12-hour, 53 inches, Belouve, La Réunion I., 28-29 February 1964	*Ibid.*
World, 24-hour, 74 inches, Cilaos, La Réunion I., 15-16 March 1952	*Ibid.*
Northern Hemisphere, 24-hour, 49 inches, Paishih, Taiwan, 10-11 September 1963	*Ibid.*
Yankeetown, Florida, had a 24-hour rainfall of 39 inches, 5-6 September 1950	R. J. Schmidli, *Weather Extremes*, Salt Lake City, Utah, U.S. National Oceanic and Atmospheric Administration, National Weather Service, November 1971. (NOAA Tech Memo WR-28 and Western Region Tech Memo No. 28.)
Dharampuri, India, had a 24-hour rainfall of 39 inches, 2 July 1941	Indian Central Meteorological Research Institute, Poona, India. Communication from Director to P. A. Siple, Scientific Advisor to Director of Army Research, transmitted from Dr. Siple to Dr. W. B. Brierly, Earth Sciences Laboratory, U.S. Army Natick Laboratories, in letter dated 17 January 1962.
Australia, 24-hour, 36 inches, Crohamhurst, Queensland, 3 February 1893	B. W. Newman, Australia's Highest Daily Rainfall, *Australian Meteorol Mag*, No. 20, pp. 61-65, March 1958.
Canada, 24-hour, 19 inches, Ucluelet, British Columbia, 6 October 1967	J. G. Potter, Record Precipitation on One Day in Canada, CDS #1-68, Canada, Meteorological Branch, Toronto, 1968.
World, 5-day, 152 inches, Cilaos, La Réunion I., 13-18 March 1952	J. L. H. Paulhus, *op. cit.*

Weather Records — With Documentation by Element (Cont'd)

Element (to nearest whole number)	Reference
World, 1-month, 366 inches, Cherrapunji, India, July 1861	*Ibid.*
World, 12-month, 1042 inches, Cherrapunji, India, August 1860 to July 1861	*Ibid.*
U.S., 12-month, 624 inches, Mt. Waialeale, Kauai, Hawaii, 24 July 1947 to 27 July 1948	R. J. Schmidli, *op. cit.*
B. Greatest Average Yearly Precipitation	
World, 460 inches during a 32-year period, Mt. Waialeale, Kauai, Hawaii	U.S. Environmental Science Services Administration, Environmental Data Service, *Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area*, October 1968. (ESSA/ PI680032.)
Asia, 450 inches during a 74-year period, Cherrapunji, India	*Ibid.*
Africa, 405 inches during a 32-year period, Debundscha, Cameroon	*Ibid.*
South America, 354 inches during a 10-16 year period, Quibdo, Colombia	*Ibid.*
North America, 262 inches during a 14-year period, Henderson Lake, British Columbia	*Ibid.*
Europe, 183 inches during a 22-year period, Crkvice, Yugoslavia	*Ibid.*
Australia, 179 inches during a 31-year period, Tully, Queensland	*Ibid.*
Bahia Felix, Chile, has an average of 325 days/year with rain	L. H. Seamon and G. S. Bartlett, Climatological Extremes, *Weekly Weather and Crop Bull*, Vol. 43, No. 9, pp. 6-8, 27 February 1956.
C. Least Precipitation	
Arica, Chile, had no rain for more than 14 consecutive years, October 1903 through December 1917	R. J. Schmidli, *op. cit.*

Weather Records -- With Documentation by Element (Cont'd)

Element (to nearest whole number)	Reference
U.S. longest dry period, 767 days, Bagdad, California, 3 October 1912 to 8 November 1914.	L. H. Seamon and G. S. Bartlett *op. cit.*
D. Lowest Average Yearly Precipitation	
World, .03 inch during a 59-year period, Arica, Chile	U.S. Environmental Science Services Administration, Environmental Data Service, ***Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area,*** October 1968. (ESSA/ PI680032.)
Africa. <0.1 inch during a 39-year period, Wadi Halfa, Sudan	*Ibid.*
North America, 1.2 inches during a 14-year period, Bataques, Mexico	*Ibid.*
U.S., 1.63 inches, Death Valley, California	M. A. Arkin, *op. cit.*
Asia, 1.8 inches during a 50-year period, Aden, South Yemen	U.S. Environmental Science Services Administration, Environmental Data Service, ***Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area,*** October 1968. (ESSA/ PI680032.)
Australia, 4.05 inches during a 34-year period, Mulka, South Australia	*Ibid.*
Europe, 6.4 inches during a 25-year period, Astrakhan, U.S.S.R.	*Ibid.*
E. Variability of Precipitation	
Debundscha, Cameroon, has 75 inches average variability of annual precipitation	E. Biel, Die Veränderlichkeit der Jahressumme des Niederschlags auf der Erde [The Variability of the Yearly Amount of Precipitation of the Earth]. Geographische Jahrbuch aus Oesterreich, Leipzig, vols. 14 and 15, pp. 151-80, 1929.
Themed, Israel, has a 94% relative variability of annual precipitation	J. Katsnelson and S. Kotz, On the Upper Limits of Some Measures of Variability. *Archiv fur Meteorologie, Geophysik Und Bioklimatologie*, Ser B., Vol. 8, pp. 103-107, 1958.

Weather Records – With Documentation by Element (Cont'd)

Element (to nearest whole number)	Reference
Lhasa, Tibet, had a 108% relative variability of annual precipitation, 1935-1938	A. Lu, A Brief Survey of the Climate of Lhasa, *Quarterly J Roy Meteorol Soc*, Vol. 65, No. 281, pp. 297-302, 1939.
F. Hailstones	
U.S. largest hailstone, 17.5 inches circumference, Coffeyville, Kansas, 3 September 1970	The "New Champ" Hailstone, *Weatherwise*, Vol. 24, No. 4, p. 151, 1971.
G. Greatest Snowfall	
North America, 24-hour, 76 inches, Silver Lake, Colorado, 14-15 April 1921	R. J. Schmidli, *op. cit.*
Alaska, 24-hour, 62 inches, Thompson Pass, 29 December 1955	*Ibid.*
Bessans, France, had a snowfall of 68 inches in 19 hours, 5-6 April 1969	M. Jail, Un remarquable effet de lombarde: les chutes de neige de Paques 1969 en Haute-Maurienne, *Revue de Géographie Alpine*, Grenoble, Vol. 57, No. 3, pp. 613-21, 1969.
Canada, observation day, 44 inches, Livingston Ranger Station, Alberta, 29 June 1963	R. J. Schmidli, *op. cit.*
North America, one storm, 189 inches, Mt. Shasta Ski Bowl, California, 13-19 February 1959	*Ibid.*
Alaska, one storm, 175 inches Thompson Pass, 26-31 December 1955	*Ibid.*
North America, one season, 1122 inches, Rainer Paradise Ranger Station, Washington, 1971-72	New U.S. Record Snowfall, *Weatherwise*, Vol. 25, No. 4, p. 173, 1972.
Alaska, one season, 974 inches, Thompson Pass, 1952-1953	R. J. Schmidli, *op. cit.*
Canada, one season, 880 inches, Kemano, Kildala Pass, British Columbia, 1956-1957	*Ibid.*

Weather Records – With Documentation by Element (Cont'd)

Element (to nearest whole number)	Reference
U.S. greatest depth of snow on the ground, 451 inches, Tamarack, California, 11 March 1911	*Ibid.*
III. Other Elements	
A. Thunderstorms	
Kampala, Uganda, averages 242 thunderstorm days per year	World Meteorological Organization, *World Distribution of Thunderstorm Days.* (OMM, No. 21.) Geneva, Switzerland, 1953.
Bogor, Indonesia, averaged 322 thunderstorm days per year, 1916-1919	V. I. Arabadzhi, Klimat i grozy [Climate and Thunderstorms], *Priroda*, No. 2, pp. 65-66, 1966. (Translated by E. R. Hope as Canada Defence Research Board Translation T456R, April 1966.)
B. Sea-Level Air Pressure	
World, highest, 32.01 inches, Agata, U.S.S.R., 31 December 1968	Extremes of Atmospheric Pressure, *Weatherwise*, Vol. 24, No. 3, pp. 130-31, 1971.
North America, highest, 31.52 inches, Medicine Hat, Alberta, 24 January 1897	R. J. Schmidli, *op. cit.*
World, lowest, 25.90 inches, estimated by aerial reconnaissance in the eye of Typhoon Ida at 19°N, 135°E, 24 September 1958	*Ibid.*
North America, lowest, 26.35 inches, Matecumbe Key, Florida, 2 September 1935	*Ibid.*
C. Solar Radiation	
South Pole has 955 langleys average daily insolation in December	U.S. Environmental Science Services Administration, Environmental Data Service, *Climatological Data for Antarctica Stations*, Nos. 1 and 9, Washington, D.C., GPO, 1962 and 1968.
Malange, Angola, had 113 langleys in 1 hour, 7 November 1961	*Quart Radiation Bull, Union of South Africa*, Vol. 8, No. 2, p. 160, 1961.

Weather Records — With Documentation by Element (Cont'd)

Element (to nearest whole number)	Reference
D. Wind Speed	
World, highest peak gust, 231 miles per hour, Mt. Washington, New Hampshire, 12 April 1934	U.S. Environmental Science Services Administration, Environmental Data Service, Local Climatological Data; Annual Summary with Comparative Data, 1967, Mount Washington Observatory, Gorham, New Hampshire, Washington, D.C., GPO, 1968
Thule Air Base, Greenland, had a peak gust of 207 miles per hour, 8 March 1972	J. R. Stansfield, The Severe Arctic Storm of 8-9 March 1972 at Thule Air Force Base, Greenland, *Weatherwise*, Vol. 25, No. 5, pp. 228-33, 1972.
Miyakojima I., Ryukyu Islands, had a peak gust of 190 miles per hour, 5 September 1966	Y. Mitsuta and S. Yoshizumi, Characteristics of the Second Miyakojima Typhoon, *Kyoto, Japan. Univ. Disaster Prevention Research Institute. Bulletin*, Vol. 18, pt. 1, No. 131, pp. 15-34, 1968.
World, highest 5-minutes, 188 miles per hour, Mt. Washington, New Hampshire, 12 April 1934	R. J. Schmidli, *op. cit.*
Port Martin, Antarctica, had a 24-hour mean of 108 miles per hour, 21-22 March 1951 and a mean monthly of 65 miles per hour, March 1951.	F. Loewe. The Land of Storms, *Weather*, Vol. 27, No. 3, pp. 110-121, 1972.
U.S. highest annual mean, 35 miles per hour. Mt. Washington, New Hampshire	M. A. Arkin, *op. cit.*
E. Dew Point (Humidity)	
Assab, Ethiopia has 84°F mean afternoon dew point in June	A. V. Dodd, Areal and Temporal Occurrence of High Dew Points and Associated Temperatures, Tecn Rpt ES-49, U.S. Army Natick Laboratories, Natick, Massachusetts, August 1969.
F. Fog Frequency	
U.S. West Coast highest average, 2552 hours per year, Cape Disappointment, Washington	M. A. Arkin, *op. cit.*
U.S. East Coast highest average, 1580 hours per year, Moose Peak Lighthouse, Mistake Island, Maine	M. A. Arkin, *op. cit.*

II. COMMENTARY ON RELIABILITY OF THE RECORDS

To insure comparability of meteorological observations, various regulations concerning site, instrumentation, and procedure have been established by the World Meteorological Organization.[2] Observations taken in accordance with these regulations, over which some sort of quality control is exercised to correct observational errors that might appear, would be accepted by the national meteorological agencies.[3] Also, for highest or lowest average records, the period of observation should be long enough to be representative. However, even after records have been accepted by appropriate agencies, their reliability is still sometimes questioned.

An extreme phenomenon observed and recorded in conformance with prescribed procedures and accepted by the appropriate meteorological service represents only the most extreme acceptable record that is available. It is not necessarily – or even probably – the most extreme value that could occur or ever has occurred. According to M. A. Arkin, "... record extremes must be taken with a grain of salt . . . ."[4] He explains that news of an extreme weather occurrence is not always widely disseminated, meteorological records are relatively short, stations are very few, and "... even the densest network of stations provides only a very small sample of the weather . . . ." To this it can be added that records may be established which the observers do not recognize as records, and sometimes suspected records are not verified because of difficulties in validating.

3. **Temperature.** Air temperatures are measured at standard heights varying in different countries from 4 to 6 feet above ground level. The values obtained can be affected by radiation from the sun, sky, earth, and other surrounding objects, and precautions need to be taken to protect the measuring instruments from radiation. In addition, adequate ventilation must be provided to insure representation of the circulating air. In addition to these requirements concerning height, radiation protection, and ventilation, there are requirements pertinent to construction and accuracy (manufacturing tolerance) of the measuring instruments.

Daily maximum and minimum temperatures are recorded at more than 10,000 weather stations throughout the world.[5] Maximum and minimum thermometers which stay at the highest or lowest point, respectively, reached during the reading period are used to record these temperatures. Maximum thermometers are generally of the mercury-in-glass type. But since mercury freezes at about -32°F, minimum thermometers contain

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[2] World Meteorological Organization, "Guide to Meteorological Instrument and Observing Practices," 2nd ed., Geneva, 1961. (WMO-No. 8. TP. 3.)

[3] M. A. Arkin, *op. cit.*

[4] M. A. Arkin, *op. cit.*

[5] G. Hoffman, "Die höchsten and die tiefsten Temperaturen auf der Erde," (The Highest and Lowest Temperatures of the Earth). *Umschau*, Frankfurt am Main, Vol. 63, No. 1, pp. 16-18, 1 Jan 63.

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other liquids such as ethyl alcohol; these are commonly called spirit thermometers because of the type of liquids used.

Besides the absolute maximum and minimum temperatures ever recorded in an area, several other kinds of extreme temperature records can be of interest. Among these are the highest and lowest mean daily, monthly, or yearly temperatures; the highest and lowest mean daily, monthly, or yearly maximum and minimum temperatures; the longest durations of very high or very low temperatures; the greatest variations in a given period (e.g., between summer and winter, day and night); and the fastest rises and falls in temperature during short periods of time.

a. **High Temperatures.** Factors favorable to occurrence of very high temperatures have been listed by the British meteorologist H. H. Lamb.[6] Among these factors are strong heating of the surface, especially desert sand or bare rock, during times of high sun and very clear atmosphere; a long period of time during which the air has passed or remained over extremely warm surface; inhibition of vertical convection or local circulations by subsidence; passage of the air over mountains, especially when latent heat absorbed during condensation or rainfall on the ascent is released into the descending air; and advection from places where the air was already heated.

Lamb's investigations suggest that conjunction of most or all of these influences might occur during record high extremes, and that many of the peak temperatures "... are associated with the speeding up, and longer fetch, of warm air advection just ahead of a cold front ...." Further, he concludes that these extreme high temperatures "... may have been very local and associated with some locally forced turbulence – for instance, in air descending some sort of declivity or merely passing over town buildings – the circumstances being such as to raise adiabatically by a degree or two the temperature of already very warm air at a slightly higher level ...."[7]

The highest possible temperature that could occur has been considered by the German meteorologist Hoffman.[8] According to him, because warm air is lighter, air near the hot ground surface seeks to rise above overlying layers which are cooler. Thus, an ascending air stream is established through which the hot air escapes so that the temperature of the lower air levels should not rise above a theoretically definable value. He puts this value at slightly over 55°C (131°F) and states that world weather observations confirm it. The highest accepted record is 58°C (136°F), at El Azizia in North Africa, but claims have been made of higher temperatures; e.g., 140°F at two

[6] H. H. Lamb, "The Occurrence of Very High Surface Temperatures," *Meteorol. Mag.*, London, Vol. 87, No. 1028, pp. 39-43, 1958.

[7] *Ibid.*,

[8] G. Hoffman, *op. cit.*

Mexican stations, Delta, Baja California and Riito, Sonora[9] and 167°F in the Gobi Desert of interior Asia.[10]

The highest mea   rly maximum temperatures, 122°F or above, occur in the northern and wes   ara; Death Valley, California; low-lying desert areas in Iran; and a small part f western Pakistan.[11] By contrast, the highest yearly maximum temperatures in some parts of Antarctica average below 0°F.

World's highest temperature: 136°F
El Azizia, Libya, 13 September 1922

El Azizia is located in the northern Sahara at 32°32′ N, 13°01′ E, elevation 367 feet.[12] At least 30 years of observations are available for the station,[13] and the climate has been described by Eredia.[14] The world record temperature occurred during the month of September; other months during which very high maximum temperatures have occurred are August and June, with 133°F and 127°F, respectively.[15]

Although this record of 58°C has attained general acceptance as the world's highest temperature recorded under standard conditions,[16],[17] it has been questioned. A. Fántoli, who was Director of the Libyan Meteorological Service at the time the observation was reported, has written about the subject,[18] [19] and summaries in English are available.[20] [21] Although he was unable to personally investigate the reliability of the reading at the time it occurred, he has since examined the evidence in some detail: the exposure; effect of instrument shelter or of instrumental error; records for pressure, wind, and humidity at three other stations in Tripoli for 9-12 September 1922; and synoptic charts for the area for 10-14 September 1922. He also

9 International Boundary and Water Commission, United States and Mexico, "Flow of the Colorado River and other Western Boundary Streams and Related Data," p. 58, Western Water Bulletin, 1964.

10 H. T. Ashton and J. V. Maher, "Australian Forecasting and Climate," 6th ed., Melbourne, Australia, 1960.

11 G. Hoffmann, *op. cit.*

12 Great Britain, Air Ministry, Meteorological Office, "Tables of Temperature, Relative Humidity and Precipitation for the World. Part IV, Africa, the Atlantic Ocean South of 35° N and the Indian Ocean," (M.O. 617d). London Her Majesty's Stationery Office, 1958.

13 *Ibid.*

14 F. Eredia, "Klima von Azizia (Climate of Azizia," Meteorol Zeitschrift, Braunschweig, Vol. 42, p. 294. 1925.

15 Great Britain, Air Ministry, Meteorological Office, *op. cit.*

16 U. S. Environmental Science Services Administration, Environmental Data Service, *Temperature Extremes*, revised May 67 (L.S. 5821).

17 L. H. Seamon, and G. S. Bartlett, "Climatological Extremes," Weekly Weather and Crop Bulletin, Vol. 43, No. 9. pp 6-8, 27 Feb 56.

18 A. Fántoli, "La Piu Alta Temperatura del Mondo." (The Highest Temperature in the World). Rev Meteorol Aeronautica, Rome, Vol. 18, No. 3, pp 53-63, Jul-Sep 58. (English Summary)

19 A. Fántoli, "I Valori Medi Della Temperatura in Libia," Boll. Soc. Geogr. Italiana, ser. 8, Vol. 7; pp 59-71, 1954.

20 J. Gentilli, "Libyan Climate," Geograph Rev, Vol. 45, No. 2, p 269. Apr 55.

21 Meteorol Abstracts, 10 (10), 1959. (Contains abstract of # 18.)

reviewed temperature records at El Azizia for June to October 1914-1922, as well as the maximum temperatures (99°F to 118°F) at 10 places in Tripoli on 11-14 September 1922. From his investigations, Fántoli concluded that although there was an unusually violent and persistent ghibli[22] at the time, the probable or tentative maximum on 13 September 1922 was 56°C (132.8°F). This conclusion may have been influenced in part by the comparatively low maximum temperatures at nearby stations, a point also mentioned by other authors.[23] Lamb also investigated the El Azizia record, and from his investigations he has described the synoptic situation which caused the extreme heat.[24] A cold front was advancing eastward from Algeria, and advection of warm air from the Saharan interior was established some distance ahead of the front. Tripoli had strong southerly winds for two successive days before the front passed. Rainfall in mountains to the south in the Anderas area (17° N, 8° E) was thought to have contributed latent heat of condensation to the air mass.

Western Hemisphere's highest temperature: 134°F
Death Valley, California, 10 July 1913

Death Valley, at 37° N, 117° W, is a desert below sea level, flanked by mountains. It has the hottest summers in the Western Hemisphere.[25] The temperature of 134°F, recorded at Greenland Ranch Station, is accepted by the U.S. Weather Bureau as an official record. On the day this temperature occurred, winds were strong, there were sandstorm conditions, and a heat spell of 8 consecutive days with maximums of 127°F or higher was in progress.[26]

A. Court[27] has examined the Death Valley record in detail: the surrounding environment, the equipment and procedures used for taking the observation, weather conditions at the time it occurred, and temperature frequencies at the station over a period of record from 1911 through 1947. He found that at the time of the record there were comparatively low maxima at other stations in the area, as had been the case at El Azizia. He found that aside from the period during which the record occurred in July 1913, temperatures of 127°F or higher were reached in only two other years from 1911 through 1947. During a later period, 1948 to 1967, a temperature of 129°F was

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22 A ghibli is a hot, dust-bearing wind in Tripolitania.

23 G. Hellmann, "Grenzwerte der Klimaelemente auf der Erde." [Limits of Climatic Elements of the Earth]. Sitzungsberichte Preuss. Akademie der Wissenschaft, Phys. mathem. Klasse, 1925, pp. 200-215. Cited by Mark Jefferson: "Limiting Values of Temperature and Rainfall Over the World," Geograph Rev, Vol. 16: pp. 324-26, 1926.

24 H. H. Lamb, *op. cit.*

25 U. S. Environmental Science Services Administration, *Temperature Extremes, op. cit.*

26 L. Williams, "A Contribution to the Philosophy of Climatic Design Limits for Army Materiel: Extreme Hot-Desert Conditions," Technical Report ETL-TR-72-5, U. S. Army Engineer Topographic Laboratories, Fort Belvoir, Va., 1972.

27 A. Court, "How Hot is Death Valley?" *Geograph Rev*, Vol. 39, No. 2, pp 214-20, Apr 49.

reported in July 1960[28]; but according to Williams this value is doubtful.[29] From his analysis of the 1911 through 1947 data, Court determined that a temperature of 134°F has an expectancy of only once in 650 years.[30] He concluded that "constantly increasing accuracy in weather observations and higher standards of instrument exposure make it seem probable that no future official observation will exceed the present high temperature record for North America now held by Death Valley."[31]

Persian Gulf had a sea-surface temperature of 96°F
5 August 1924.

This sea surface temperature, measured by the SS Frankenfels, is " . . . among the highest recorded. . . ."[32] However, sea temperature in the Persian Gulf has been known to reach 98°F in August and September.[33] Although the 96°F record is not an absolute maximum in the sense of being the highest known, it was suggested for inclusion here to indicate how hot the sea surface can become. The Persian Gulf also has very high average temperatures in summer, 88°F during July and August.[34]

Dallol, Ethiopia, has an annual mean temperature of 94°F,
possibly the world's highest.

Places that are hot in summer and remain warm in winter have high annual means of daily maximum temperature. The highest occur at low elevations, away from coasts, and within the latitude belt between 12° and 20°N across Africa and possibly the southwestern Arabian penisula.[35] Dallol is within this belt at 14°19′ N, 40°11′E. It is located 258 feet below sea level on the edge of the Danakil Depression, a salt desert. By averaging the annual mean daily maximum temperature of 106°F[36] and the annual mean daily minimum of 83°F,[37] an annual mean temperature of 94°F is obtained. All of these values are possible world records. The 94°F annual mean

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[28] P. I. Tattelman, N. Sissenwine and R. W. Lenhard, "World Frequency of High Temperature," Environmental Research Papers, No. 305, Air Force Cambridge Research Laboratories, Bedford, Mass., 1969.

[29] L. Williams, *op. cit.*

[30] A. Court, *op. cit.*

[31] *Ibid.*

[32] U. S. Environmental Science Services Administration, *Temperature Extremes, op. cit.*

[33] Great Britain, Air Ministry, Meteorological Office, "Weather in the Indian Ocean to Latitude 30°S and Longitude 95°E including the Red Sea and Persian Gulf," volume II "Local Information," part 3, "The Persian Gulf and Gulf of Oman including the part of the Makran Coast west of Gwadar," (M. O. 451b), His Majesty's Stationery Office, London, 1941.

[34] U. S. Environmental Science Services Administration, *Temperature Extremes, op. cit.*

[35] D. E. Pedgley, "Air Temperatures at Dallol, Ethiopia," *Meteorol Mag*, London, Vol. 96, No. 1142, pp. 265-71, Sep 67.

[36] *Ibid.*

[37] *Ibid.*

exceeds the 88°F averaged at Lugh Ferrandi, Somalia from 1923 to 1935 and cited as probably the world's highest annual mean temperature.[38] The 106°F annual mean daily maximum temperature exceeds the 102°F recorded at Abecher, Chad for a 6-year period and the 101°F at Merowe, Sudan (30 years) and Araoune, Mali (8 years): these values are the highest listed in the British Meteorological Office's "Tables of Temperature, Relative Humidity and Precipitation for the World."[39]

The Dallol temperatures were obtained from readings taken at a climatological station maintained at the base camp of an American prospecting company over a period of 6 years, October 1960 through November 1966. Maximum and minimum temperatures were recorded ". . . using standard thermometers kept at a height of four feet in a ventilated screen . . . ."[40] The period of observation is short; but it is believed that the difference between these available 6-year values and a long-term mean would be very small. At nearby Khormaksar, whose temperature trends appear similar to Dallol's, the greatest difference between monthly means of daily maximum temperature for the years 1961 through 1966 and those for 1947 through 1966 was only 0.3°C.[41]

D. E. Pedgley has considered areas where annual mean daily maxima might equal or exceed Dallol's.[42] According to him, in the lowest part of the Danakil Depression, which reaches a minimum of about 390 feet below sea level some 20 miles south of Dallol, the annual mean daily maximum might be a "fraction of a degree Fahrenheit greater" than at Dallol.[43] In the Abecher area where there is a ". . . descent of potentially warmer air resulting from a blocking by the Marra Mountains of the north-easterlies that blow for much of the year . . . ." there might also be low-lying places with values similar to Dallol's.

b. **Low Temperatures.** Extreme low temperatures result from ". . . the simultaneous occurrence of an optimum combination of several meteorological elements; absence of solar radiation, clear skies, and calm air are the most essential requirements, with the ultimate fall in temperature dependent upon the duration of these conditions . . . ."[44] During such conditions, there is minimum mixing of the vertical air layers. As the ground surface loses heat through terrestrial radiation, the nearest air layers become cooled and, consequently, heavier than the layers above them.

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[38] U. S. Environmental Science Services Administration, *Temperature Extremes, op. cit.*

[39] Great Britain, Air Ministry, Meteorological Office, *op. cit.*

[40] D. E. Pedgley, *op. cit.*

[41] *Ibid.*

[42] *Ibid.*

[43] *Ibid.*

[44] R. A. McCormick, "An Estimate of the Minimum Possible Surface Temperature at the South Pole," *Monthly Weather Rev.*, Vol. 86, No. 1, pp. 1-5, Jan 58.

Extremely cold temperatures occur in interior high latitude localities with clear skies, which are conducive to maximum terrestrial radiation, and with topographic features which afford protection from wind. Geographic areas of extreme cold are the eastern Antarctic plateau (approximately 9,000 to 12,000 feet of in elevation): the central part of the Greenland Icecap (approximately 8,200 to 9,800 feet in elevation); Siberia between 63° and 68°N and between 93° and 160°E (below 2,500 feet in elevation); and the Yukon basin of northwestern Canada and Alaska (below 2,500 feet in elevation).

In Europe, the lowest temperature has been recorded at Ust'Shchugor in the Soviet Union at about 55°N, 50°E.[45] This station, located near the Siberian border at an elevation of 279 feet, reported a -67°F in January; the exact date is not cited, but it was the lowest in a 15-year period.[46]

Annual mean minimum temperature can range from approximately 70°F in places like Dallol, Ethiopia, to a possible -130°F in the Antarctic. This difference of about 200 Fahrenheit degrees is considerably greater than the difference of about 125 Fahrenheit degrees between the highest and lowest annual mean maximum temperatures. Annual mean minimums for the world's coldest areas are -76°F in Siberia, below -85°F on the Greenland Icecap, and from about -94°F to -130°F in the Antarctic.[47] The -130°F value is considered possible as an annual mean minimum, even though -127°F is the lowest temperature recorded, because in the extensive cold area of East Antarctica only a few stations have taken temperature measurements and then only for short periods of time.[48]

World's lowest temperature: -127°F
Vostok, Antarctica, 24 August 1960

The theoretical minimum temperature that could be reached has been calculated by Shliakhov[49] and by McCormick.[50] Shliakhov estimated -80°C ±2°C at about 4 kilometers altitude (i.e., -112°F at about 13,123 feet) with a decrease of 0.5°C for every further 100-meter rise in height. This estimate was exceeded when the temperature fell to -87.4°C (-125°F) at Vostok, Antarctica (78°27'S, 106°52'E, elevation 11,220 feet) in 1958 and again in 1960 when the world record low temperature of

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45 U.S. Environmental Science Services Administration, Environmental Data Service, *Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area*, Oct 68 (ESSA/PI 680032).

46 *Ibid.*

47 G. Hoffmann, *op. cit.*

48 *Ibid.*

49 V. I. Shliakhov, "O Minimal'nykh Temperaturakh v Antarktide [On Minimum Temperatures in Antarctica]," Meteorologiia i Gidrologiia, No. 4, pp. 5-7, 1958.

50 R. A. McCormick, *op. cit.*

-126.9°F occurred, also at Vostok. The basic error in Shliakhov's calculations, according to H. Wexler[51] resulted from associating a zero radiation balance with a certain temperature – the theoretical minimum. McCormick's calculation for the possible minimum was for "... virtually optimum conditions ... assumed to persist during the polar night (about 180 days) ... ." [52] The resultant value, -200°C (-328°F) is "... hardly realistic for the troposphere ..." where, apparently, wintertime radiative energy losses are compensated by advective gains. However, it might be more applicable to the ozonosphere where such "... energy-balancing processes are not equally operative ... ." [53] An ozonospheric temperature of -97°C (-143°F) was measured at about 24,000 meters (78,740 feet) above Halley Bay at 75°31'S, 26°36'W, altitude 98 feet, on 9 August 1959.[54] The lowest temperature recorded in the Earth's atmosphere is -153°C at 93 kilometers above Point Barrow, Alaska, in June 1966.[55] However, this is above the ozonosphere and June is not the time of polar night at Point Barrow.

Northern Hemisphere's Lowest Temperature: -90°F
Verkhoyansk, USSR, 5 and 7 February 1892 and Oimekon, USSR, 6 February 1933

Very low winter temperatures occur in the Verkhoyansk-Oimekon cold zone, approximately between 63° and 68°N, and 93° and 160°E in the East Siberian taiga (northern coniferous forest). It is an area of extreme continentality, lying near the eastern end of the world's largest landmass and blocked off by mountain ranges from the moderating influence of oceans. In winter, the high air pressures from the Asiatic anticyclone create clear weather which promotes strong radiation from the snow surface during the long nights. A value of -89.7°F was recorded at Verkhoyansk (67°34'N, 133°51'E, elevation about 350 feet) twice in 1892, and -89.9°F was recorded at Oimekon (63°28'N, 142°49'E, elevation 2,625 feet) in 1933.[56] Oimekon is situated in a valley 10 to 20 kilometers (about 3,280 feet) wide, below a plateau which is, in turn, enclosed by mountains.[57] In the winter, cold air accumulates in the valley and there is hardly any wind. It is possible that the temperature there may have fallen

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51 H. Wexler, "Note on Lowest Antarctic Temperature Estimated by Shliakhov," *Monthly Weather Review*, Vol. 87, No. 4, p. 147, Apr 59.

52 R. A. McCormick, *op. cit.*

53 *Ibid.*

54 D. J. George, "Coldest Place on Earth," *Weather*, Vol. 16, No. 5, pp. 144-50, 1961.

55 H. Faust, "Die niedrigsten Temperaturen in der Erdatmosphäre [The lowest temperatures in the Earth's atmosphere]," Weltraumfahrt, Frankfurt am Main, Vol. 20, No. 1/2, pp. 25-27, 1969.

56 U.S. Environmental Science Services Administration, *Temperature Extremes, op. cit.*

57 A. A. Borisov, "Climates of the U.S.S.R," translated by R. A. Ledward and edited by C. A. Halstead, Chicago, Aldine, 1965.

below the value recorded; temperatures of -95°F and down to -108°F have been claimed.[58] [59] [60] Considerable controversy has arisen about the Verkhoyansk records due to problems concerning instrument corrections, and about both the Verkhoyansk and Oimekon records because of misleading references to incorrect values in the literature.[61] [62] [63]

Greenland's lowest temperature: -87°F
Northice, 9 January 1954

On the permanent icecap, which covers most of the interior of Greenland, temperatures are very low due both to loss of heat through radiation and to evaporative cooling from the snow and ice surface.[64] A temperature of -86.8°F has been recorded at Northice (78°04'N, 38°29'W, elevation 7,687 feet), a station established by the British North Greenland Expedition.[65] Since the period of record for Northice was only 20 months (November 1952 through June 1954) and temperatures below -75°F occurred 16 times, it is quite probable that temperatures there have been lower than -87°F at other times.[66]

North America's lowest temperature (excluding Greenland): -81°F
Snag, Yukon Territory 3 February 1947

Snag is located near the Alaskan border of Canada's Yukon Territory, at 62°23'N, 140°23'W, elevation 2,120 feet. This part of Canada resembles the Verkhoyansk-Oimekon Area of eastern Siberia in its continentality. The lowest gradation on the minimum thermometer which recorded this extreme was -80°F, but a pencil mark was made at a distance about 4 degrees below -80°F.[67] However, subsequent

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58 N. A. Stepanova, "On the Lowest Temperatures on Earth," *Monthly Weather Review*, Vol. 86, No. 1, pp. 6-10, Jan 58.

59 L. H. Seamon and G. S. Bartlett, *op. cit.*

60 E. A. Finn, Kak Byl Otkryt "Polius Kholoda" [How was the "Cold Pole" Discovered?]. Priroda, No. 7, pp. 85-88, Moscow, Jul 67.

61 N. A. Stepanova, *op. cit.*

62 E. S. Rubinshtein, "O Prirode Poliusov Kholoda," [On the Nature of the Cold Poles]. Vsesoiuznoe Geograficheskoe Obshchestvo Izvestiia, Vol. 91, No. 3, pp. 265-68, May-Jun 59.

63 E. S. Rubinshtein, "K Voprosu o Poliusakh Kholoda," [Contribution to the Problems of the Earth's Cold Poles]. Meteorologiia i Gidrologiia, No. 12, pp. 28-30, Dec 1968, Translated by U.S. Weather Bureau, Washington, D.C., May 59.

64 D. W. Hogue, "Environment of the Greenland Icecap," Tech Rpt ES-14, U.S. Army Natick Laboratories, Natick, Mass., Dec 64.

65 R. A. Hamilton and G. Rollitt, "British North Greenland Expedition 1952-54; climatological tables for the site of the expedition's base at Britannia Sø (Lake) and the station on the inland-ice Northice." København, C. A. Reitzels Forlag, Medd Grønland, Vol. 158, pp. 1-83, 1957.

66 R. S. Quiroz, "Lowest Temperature in Greenland," *Monthly Weather Review*, Vol. 86, No. 3, p. 99, Mar 58.

67 A. Court and H. A. Salmela, "Improbable Weather Extremes and Measurement Needs." *Amer Meteorol Soc Bull*, Vol. 44, No. 9, pp. 571-75, Sep 63.

laboratory calibration of the thermometer indicated an instrumental error of ±3 degrees: and a value of -81.4°F was officially set by the Canadian Meteorological Service.[68] [69] [70] On the preceding day, 2 February, the corrected minimum temperature was -80.1°F.[71] The previous record Canadian low temperature was -78.5°F at Fort Good Hope in the Northwest territories on 30 December 1910.[72]

U. S. lowest temperature: -80°F
Prospect Creek, Alaska, 23 January 1971

This low temperature was recorded at a camp along the Alaskan pipeline in the Endicott Mountains southeast of Bettles at 66°48'N, 150°40'W, 1,100 feet elevation. An official figure of -79.8°F was established " . . . after subsequent recalibration of the thermometer at the Bureau of Standards in Washington . . . . " [73] It replaced the previous official United States low of -76°F recorded at Tanana, Alaska, in the Yukon Valley at 65°10'N, 152°06'W, elevation 220 feet, in January 1886.[74] Among other low temperatures claimed for Alaska was one of -78°F recorded by an airways observer at Fort Yukon (66°34'N, 145°18'W, elevation 417 feet) on 14 January 1934 two days after the weather station closed there, which made the record unofficial.[75] Also, a minimum thermometer left at 15,000 feet on Mt. McKinley for 19 years indicated a temperature lower than -100°F at some time during its exposure.[76]

Plateau Station, Antarctica, had a mean July temperature of -100°F
in 1968 and a mean temperature of -70°F for 1966 through 1968

Plateau Station is located at 79°15'S, 40°30'E, elevation 11,890 feet. It is in or near the coldest part of the Antarctic, which is believed to be close to the ridge line in East Antarctica.[77] During the winter of 1968, there were 118 days with temperatures below -100°F.[78] The July mean temperature for that year is believed to be

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67 A. Court and H. A. Salmela, "Improbable Weather Extremes and Measurement Needs," *Amer Meteorol Soc Bull*, Vol. 44, No. 9, pp. 571-75, Sep 63.

68 *Ibid.*

69 N. A. Stepanova, *op. cit.*

70 A. Thomson, "Lowest Temperature in Canada," *Monthly Weather Rev*, Vol. 86, No. 8, p. 298, Aug 58.

71 *Ibid.*

72 N. A. Stepanova, *op. cit.*

73 *Weatherwise*, Apr 71, Vol. 24, No. 2, p. 94.

74 U. S. Environmental Science Services Administration, *Temperature Extremes, op. cit.*

75 L. S. Seamon and G. S. Bartlett, *op. cit.*

76 *Ibid.*

77 H. H. Lamb, "Differences in the Meteorology of the Northern and Southern Polar Regions," *Meteorol Mag*, Vol. 87, No. 1038, pp. 353-79, London, Dec 58.

78 U. S. Army Natick Laboratories," Annual Record of Major Events - FY 1969," Natick, Mass., 1969.

a new world record, -99.8°F.[79] It exceeds a mean of -97.2°F (-71.8°C) during August 1958 at Sovietskaya[80] which has been quoted as " . . . probably the lowest mean monthly temperature on record. . . . "[81] Sovietskaya, a Russian station, at 78°24'S, 87°35'E, elevation 11,713 feet, reported an annual mean temperature of -71°F during the IGY period in 1957 and 1958.[82] This is colder than Plateau Station's -70°F, but the area is not considered to be as cold. The periods of record at Plateau Station and Sovietskaya are not long enough, however, to be conclusive. Some other low average temperatures are -67°F at Vostok during 1958 and 1959, and -59°F at Amundsen-Scott Station (90°S, elevation 9,186 feet) for the period 1957-1964.[83] During this same period at Amundsen-Scott, the July temperature averaged -74.5°F with the maximums averaging -69°F and the minimums, -80°F.[84]

c. **Temperature Variations.** Rapid temperature changes can occur under certain weather conditions; e.g., changes in wind direction whether onshore or offshore in coastal areas especially during seasons of the year when land-sea temperature differences are greatest. Foehns (warm, drying winds descending the lee sides of mountain ranges) can bring substantial temperature rises in short periods of time; increases of 20 to 30 degrees in an hour are not uncommon along the eastern side of the Rocky Mountains in the United States and Canada.[85] Advection of cold air masses can cause temperature falls which can be further intensified by loss of heat through radiation. Still other weather situations can cause extreme fluctuations in temperature.

U. S. Greatest 2-minute temperature rise:
49F°, from -4°F to 45°F
Spearfish, South Dakota, 22 January 1943

Rapid City, South Dakota, had three temperature rises
and two falls of 40F° or more during a period
of 3 hours and 10 minutes, 22 January 1943

Spearfish is located at 44°30'N, 104°W, elevation 3,637 feet, and Rapid City is at 44°N, 103°W, elevation 3,234 feet. They are in the Black Hills, a dome-shaped mass culminating in peaks over 7,200 feet above sea level, which slopes abruptly on the

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79 P. C. Dalrymple, Geographic Applications Division, U. S. Army Engineer Topographic Laboratories, Fort Belvoir, Va. Personal Communication.

80 J. Alt, Quelques considérations générales sur la météorologie de l'Antarctique, *La Météorologie*, No. 57, pp. 17-42, 1960.

81 D. J. George, *op. cit.*

82 N. A. Stepanova, *op. cit.*

83 U. S. Environmental Science Services Administration, *Temperature Extremes, op. cit.*

84 *Ibid.*

85 D. M. Ludlum. *Weather Record Book, United States and Canada.* Princeton, N.J., Weatherwise, 1971.

east and gradually on the west. This region lies mostly between 43° and 45°N, and 103° and 104°30'W, and the effects of the topography on winds from the west cause rapid temperature changes to occur there rather frequently.

On 22 January 1943, very rapid and pronounced fluctuations in temperature took place in the Black Hills. The phenomenon, investigated by Hamann, was "... essentially the result of the wavering motion of a pronounced quasistationary front separating Continental Arctic air from Maritime Polar air ...." [86] Local chinook[87] effects possibly contributed to the unusual conditions. At Spearfish, the temperature rose from -4°F to 45°F and returned to -4°F between 0732 and 0927 hours (7:32 and 9:27 a.m.).[88] During this period, in which there were many abrupt changes, the record 2-minute rise occurred. At Rapid City, the temperature rose from 5°F to 54°F between 0920 and 0940 hours (9:20 and 9:40 a.m.), fell to 11°F at 1030 hours, rose to 55°F at 1045 hours, fell to 10°F at 1130 hours, rose to 34°F at 1150 hours, fell to 16°F at 1215 hours and rose to 56°F at 1240 hours.[89] Changes were so rapid that buildings were experiencing winter on one side and spring around the corner. The phenomenon also caused unusually large daily ranges in temperature, over 50 degrees at some places, and sharp contrasts between some nearby places. For example, at Lead, South Dakota, the temperature was 52°F, while at Deadwood, less than 3 miles away, it was -16°F.[90]

In Canada, similar conditions have occurred. At Pincher Creek, Alberta, on 6 January 1966, the temperature rose 45F° (from -12 to 33) and fell 40F° (from 33 to -7) during a 2-hour period.[91] Several hours later it again rose 46F° (from -10 to 36) within an hour.

4. **Precipitation.** Precipitation is measured by the depth to which it covers a horizontal unit area during a given period. Precipitation is caught in gages whose diameter represents the horizontal unit area; the more representative the catch is of actual fall over the entire observation area, the more useful the measurement. For this reason, site, form, and exposure of the gage are important, and precautions need to be taken to prevent precipitation from splashing out of the gage or being blown out by wind. In hot, dry areas, evaporation can be a problem. Various requirements to cover these points have been established by the World Meteorological Organization.[92]

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[86] R. R. Hamann, The Remarkable Temperature Fluctuations in the Black Hills Region, January 1943, *Monthly Weather Review*, Vol. 71, No. 3, pp. 29-32.

[87] A name given to foehns in the Western United States and Canada.

[88] R. R. Hamann, *op. cit.*

[89] *Ibid.*

[90] *Ibid.*

[91] D. M. Ludlum, *op. cit.*

[92] World Meteorological Organization, *op. cit.*

Gages are of two main kinds – the ordinary or non-recording gages and recording gages. The former provide a means of collecting and measuring precipitation, and the latter incorporate mechanisms for recording the amount of fall during a given period or the rate of fall at any instant. Descriptions of the many varieties of recording and nonrecording gages can be found in Middleton and Spilhaus, Meteorological Instruments.[93]

Even with the most efficient instruments, functioning perfectly and in the most favorable sites and exposures, there are still problems in obtaining representative precipitation values. The standard gage diameter is 8 inches in the United States. Therefore, the horizontal unit area covered by the measured precipitation is about 50 square inches, and measuring sites are often several miles apart. Furthermore, intense rainfall is often very localized and may be missed by the observation network. An example is described by Lautzenheiser and Fay.[94] During a rainfall in August 1959, two gages in the town of Island Falls, Maine, neither in the official Weather Bureau network, each measured 6.35 inches. The next nearest gage, about 12 miles away, measured 3.06 inches. The nearest official network gages, at Houlton approximately 20 to 25 miles northeast of Island Falls, measured 0.59 and 0.25 inch, respectively.

a. **Greatest Precipitation.** There are three general types of precipitation: convective, cyclonic, and orographic. Each has its characteristics and geographical distributions, as well as different expectations for record extremes. Convective rain results from overturning of cooler air by warmer air from below and takes the form of heavy, localized showers, such as thundershowers. Convective showers tend to be most frequent in warm areas and seasons and are responsible for many of the extreme short-period rainfalls.

Cyclonic precipitation results from mechanisms associated with low-pressure centers (cyclones) and with zones of convergence of different air masses (fronts). The most severe cyclonic storms, hurricanes or typhoons, bring very heavy and prolonged rain and are responsible for most of the extreme amounts that occur over a period of several hours or days. Certain parts of the world, mostly oceanic and coastal areas, lie along the tracks usually taken by these storms. The storms are prevalent in different areas at different times of the year; their tracks are mapped by month in the U. S. Navy's *Marine Climatic Atlas of the World.*[95]

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[93] W. E. K. Middleton and A. F. Spilhaus, *Meteorol Instruments*, 3rd ed. Univ. of Toronto Press, Toronto, 1953.

[94] R. E. Lautzenheiser and R. Fay, Heavy Rainfall at Island Falls, Maine, 28 Aug 59, *Monthly Weather Review*, Vol. 94, No. 12, pp. 711-714, Dec 66.

[95] H. L. Crutcher and O. M. Davis, *U. S. Navy Marine Climatic Atlas of the World*, v. 8, *The World.* (NAVAIR 50-1C-54). U. S. Naval Weather Service Command, 1969.

Orographic precipitation results from upward deflection of air when it strikes higher ground. This often occurs in conjunction with convective and cyclonic types and tends to increase the precipitation amounts produced by them; the increase is greatest on steep slopes. Precipitation can also increase when sharply narrowing valleys between slopes act as funnels on up-valley winds. Highlands in the path of moisture-carrying winds from warm seas have abundant and frequent precipitation; such areas have the highest average yearly rainfalls. Among them are the east- and south-facing slopes of the Himalayas, the western slopes of the Andes in Colombia, and mountain ranges along the northwest coast of North America. Annual mean precipitation values often differ slightly in different sources because of differences in the period of record. (This is also true of the average values for other meteorological elements.) The number of years on which the precipitation means included on the weather extremes maps are based are given in the table, pages 7-15. Generally, a longer period of record would be more reliable than a short one.

World's greatest 1-minute rainfall
1.23 inches
Unionville, Maryland, 4 July 1956

The U. S. Weather Bureau's investigation of this record is described by H. H. Engelbrecht and G. N. Brancato.[96] The extreme fall occurred during an afternoon of intense thunderstorms in the foothills of northern Virginia and adjacent north-central Maryland. At Unionville, the total precipitation during the storm was 3.60 inches, of which 2.84 inches fell during a 50-minute period from 1450 to 1540 hours (2:50 to 3:40 p.m.). Rainfall was measured with a recording rain gage located in satisfactory exposure. Some 13 points pertaining to functioning of the gage were considered in evaluating this record by Engelbrecht, then State Climatologist for Maryland, and T. E. Hostrander, who was Substation Inspector. An enlarged photograph of the recording rain gage chart revealed that at chart time 3:23+ the pen was at 2.47 inches on the chart scale and at chart time 3:23-, it was at 3.70 inches. It was concluded that "... 1.23 inches of precipitation occurred in an estimated period of one-minute or less ...." [97] This exceeded the previous world record 1-minute rainfall of 0.69 inch at Jefferson, Iowa, which in turn had exceeded the earlier record of 0.65 inch at Opid's Camp, California.

World's greatest 42-minute rainfall:
12 inches
Holt, Missouri, 22 June 1947

[96] H. H. Engelbrecht, and G. N. Brancato, World Record One-Minute Rainfall at Unionville, Maryland, *Monthly Weather Review*, Vol. 87, No. 8, pp. 303-306, Aug 59.

[97] *Ibid.*

G. A. Lott has examined the meteorological data available for this storm and considered the factors responsible for its remarkable intensity.[98] According to him, the storm occurred " . . . as a local intensification in a long, narrow, warm sector convective system (the leading edge of which may be interpreted as an instability line) a short distance ahead of a surface cold front . . . . " He further states that " . . . a unique factor was the tightening of the pressure gradient north of an instability-line Low, causing an extraordinarily strong low-level flow of unstable air into the pre-existing convective system . . . . "

World's greatest 12-hour rainfall:
53 inches on 28-29 February 1964
Belouve, La Réunion I

World's greatest 24-hour rainfall:
74 inches on 15-16 March 1952 and

World's greatest 5-day rainfall:
152 inches on 13-18 March 1952
Cilaos, La Réunion I

La Réunion Island is located in the Indian Ocean at approximately 21°S, 55°30'E. It is about 30 by 40 miles in extent and very mountainous, with steep slopes and narrow valleys. Sea surface temperature is highest during the tropical cyclone season, reaching 81°F in March.[99] The record-producing rainfall at Cilaos occurred during a tropical storm as did, presumably, that at Belouve and another very heavy rainfall (62.33 inches in 1 day and 136.83 in 5 days) at Aurere, in April 1958.[100] All three of these storms broke the previous 24-hour world record, 45.99 inches at Baguio in the Philippines in 1911, and the Cilaos storm broke the previous 5-day world record of 150 inches at Cherrapunji, India, in August 1841. The values given for Aurere and Cilaos were obtained from a survey of about 6 years of official published data for those places, and the February 1964 rainfall at Belouve was reported in a communication from the French Meteorological Service.[101] Since these record-breaking amounts " . . . were the result of an incomplete survey of a short period of record, there is a good chance that a more thorough survey of a longer period of record would disclose other, and perhaps, even greater, amounts of similar magnitude.[102]

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98 G. A. Lott, The World-record 42-minute Holt, Missouri, Rainstorm. *Monthly Weather Review*, Vol. 82, No. 2, pp. 50-59, Feb 54.

99 J. L. H. Paulus, Indian Ocean and Taiwan Rainfalls Set New Records, *Monthly Weather Review*, Vol. 93, No. 5, pp. 331-35, May 1965.

100 *Ibid.*

101 *Ibid.*

102 *Ibid.*

Northern Hemisphere's greatest 24-hour rainfall:
49 inches
Paishih, Taiwan 10-11 September 1963

Paishih is located at 24°33'N, 121°13'E at 5,368 feet on the island of Taiwan. Taiwan, like La Réunion, is very mountainous and is surrounded by warm ocean water, 82°F in August and September during the tropical storm season. The record rainfall, 49.13 inches, occurred during typhoon Gloria, and it was measured in a recording gage, thus adding to the reliability of the observation.[103] Rain of similar intensity fell at nearby stations during the same storm. At one of these places, Paling, total rainfall during the typhoon was greater than at Paishih, and for some durations, intensity might have been greater. However, no further information on Paling is available.

Dharampuri, India, had a 24-hour rainfall of
39 inches
2 July 1941 – possibly the world's greatest on flat terrain

Information on this rainfall extreme was obtained in 1962 by the late Paul Siple, then Scientific Advisor to the Director of Army Research.[104] Dr. Siple obtained it from the Director of the Indian Central Meteorological Research Institute of Poona, India. Dharampuri is at latitude 20.5°N in the Surat District of Gujarat. According to Siple,

> Institute personnel believe this to be a maximum rain on essentially flat terrain. Actually, it was a monsoon rain, and the Western Ghats (mountains) must have had some effect. However, the Poona meteorologists minimized the orographic influence, for the location of the rainfall was not in the immediate vicinity of high mountains.

Yankeetown, Florida, had a 24-hour rainfall of
39 inches
5 September 1950

Yankeetown is located on the west coast of Florida at approximately 29°2'N, 82°40'W and would be at or near sea level. The 38.70 inches that fell there is

[103] *Ibid.*

[104] Indian Central Meteorol Research Inst, Poona, India. Communication from Director to P. A. Siple, Scientific Advisor to Director of Army Research, transmitted from Dr. Siple to Dr. W. B. Brierly, Earth Sciences Laboratories, U. S. Army Natick Laboratories, in letter dated 17 Jan 62.

North America's greatest 24-hour rainfall and could be a rival claim to Dharampuri's for rainfall on nonmountainous terrain. Although this is not an official record, it is one of the "few well-accepted unofficial extremes" included by Schmidli.[105]

Australia's greatest 24-hour rainfall:
39 inches
Crohamhurst, Queensland 3 February 1893

This record, discussed by Newman, is officially accepted and apparently quite reliable.[106] It occurred during a cyclonic storm in which comparable heavy rain fell at nearby stations.

World's greatest annual mean precipitation:
460 inches
Mt. Waialeale, Kauai, Hawaii

According to official sources, " . . . normal annual precipitation at Mt. Waialeale is 460 inches, the highest recorded annual average in the world . . . . "[107] This amount is based on data for the period from 1931 through 1960. An average of 472 inches has been quoted in other sources, based on data for 1912 through 1949.[108] Mt. Waialeale also had the greatest precipitation for 1 year of any place in the United States, 624 inches between 24 July 1947 and 27 July 1948.[109] This mountain is located on the island of Kauai, at 22°04'N, 159°30'W. Conditions pertinent to the record rainfall are described by Henning.[110] According to him, the storage rain gage is at an elevation of 1,547 meters (5,075.5 feet), and measurements are made at 3-month intervals.

Asia's greatest annual mean precipitation:
450 inches
Cherrapunji, India

When the summer monsoon depressions (moderately vigorous, warm-cored cyclonic disturbances accompanied by heavy rain) from the Bay of Bengal reach the Himalayas, the rainfall is further increased by orographic lifting.[111] As a result of these monsoon disturbances, which are still not fully understood, the eastern Himalayan

105 R. J. Schmidli, *op. cit.*

106 B. W. Newman, Australia's Highest Daily Rainfall, *Australian Meteorol Mag*, No. 20, pp. 61-65, Mar 1958.

107 U. S. Environmental Science Services Administration, Environmental Data Service, *Local Climatological Data:* annual summary with comparative data, 1967, Lihue, Hawaii. Washington, D. C., GPO, 1968.

108 L. H. Seamon and G. S. Bartlett, *op. cit.*

109 R. J. Schmidli, *op. cit.*

110 D Henning, Mt. Waialeale, *Wetter und Leben*, Vienna, Vol. 19, No. 5/6, pp 93-100, 1967.

111 J. M. Walker. The Monsoon of Southern Asia: a review. *Weather*, Vol. 27, No. 5, pp. 178-89, 1972.

foothills are very wet regions. Cherrapunji is located in this area at 25°02'N, 91°08'E., 4,309 feet in elevation. The annual precipitation record there is based on a 74-year period.[112] In addition to the Asian record for annual mean precipitation, Cherrapunji also holds records for the world's greatest rainfalls for various durations of from 15 days to 2 years.[113] Among these are the greatest rainfalls in 1 month, 366 inches in July 1861, and in 12 months, 1042 inches from August 1860 to July 1861. The greatest amount for a calendar year at Cherrapunji is 905.1 inches and the least, 282.6 inches.[114] Another place in this Himalayan region, Mawsynram, Assam, could be a rival to Cherrapunji.[115]

South America's greatest annual mean rainfall
354 inches
Quibdó, Colombia

Quibdó is situated at an elevation of 120 feet at 5°41'N, 76°40'W. A rainfall average of 413 inches at Quibdó, based on data from 1931 through 1946 taken from Colombian sources,[116] [117] was cited on the 1964 revision of the *Weather Extremes* map. Earlier maps cited a value of 342 inches at Buena Vista, Colombia.[118] The value of 354 inches, shown on the current revision, was obtained from Environmental Data Service.[119]

North America's greatest annual mean precipitation
262 inches
Henderson Lake, British Columbia

This station was at a fish hatchery, now closed, at the head of Henderson Lake on the west coast of Vancouver Island at 49°08'N 125°08'W, elevation 12 feet. The topography there contributes to extreme rainfall through orographic lifting reinforced by convergence.[120] Mountains to the north and northwest of the station are

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112 U. S. Environmental Science Services Administration, *Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area. op. cit.*

113 J. L. H. Paulhus, *op. cit.*

114 U. S. Environmental Science Services Administration, *Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area, op. cit.*

115 A. M. Riabchikov, Cherrapundzhi ili Mansinram-samoe dozhdlivoe mesto na Zemle? [Cherrapunji or Mawsynram – Which is the Rainiest Spot on Earth?] Moscow, Universitet, Vestnik, Ser 5, Geografiia, Vol. 25, No. 3, pp. 79-81, 1970.

116 Colombia, *Bol Agri*, between 1929 and 1947.

117 Colombia, Departmento de Irragación, Sección de Meteorológico y Afros. *Anuar meteorol.* 1934-1947.

118 L. H. Seamon and G. S. Bartlett, *op. cit.*

119 M. A. Arkin, Chief, Foreign Branch, Environmental Data Service, U.S. Environmental Science Services Administration, correspondence dated 6 Oct 69.

120 J. G. Potter, *Record Precipitation on One Day in Canada*, CDC #1-68. Canada, Meteorological Branch, Toronto, 1968.

at right angles to the main inflows of moist air. A direct onshore flow of moist air may be deflected by the mountains and converge in the Henderson Lake area. During these conditions, it is also likely that the outflow in the lowest level from Juan de Fuca Strait adds to the convergence. A nearby station, Ucluelet Brynnor Mines, had the greatest 1-day precipitation in Canada, 19.26 inches. Henderson Lake had the second greatest amount, 16.61 inches,[121] as well as North America's greatest precipitation in 1 year, 320 (319.78) inches in 1931.[122]

b. Least Precipitation. Generally, areas of low precipitation occur in continental interiors, on lee sides of high mountains, on coasts adjacent to cool currents, in zones of higher atmospheric pressure where the air is subsiding, and in high latitudes. Arid areas are found in east Africa and adjacent southwest Asia between 15° and 35°N, western South America between 5° and 30°S, eastern South America between 35° and 50°S, western Africa between 15° and 35°S, western and interior Australia, interior Asia, parts of western North America between 25° and 40°N, and in the polar regions. As with records of high average precipitation, those of low average precipitation vary according to the years on which they are based and tend to be more reliable for a longer period. In some very dry areas, e.g., Chile and Sudan, several years can pass with no precipitation.

c. Precipitation Variability. Variations in precipitation can be upward; i.e., occurrence of above-average amounts, or downward; i.e., occurrence of below-average amounts or even drought. Among the factors causing them are displacements of ocean currents and differences in strength of the monsoonal circulation from year to year. Coasts adjacent to cold currents are generally dry, but if the current deviates even slightly, making room for warmer water, relatively abundant rainfall can occur, as in the coastal areas of Chile and Peru. Disastrous droughts in northeast Brazil might be due to the opposite occurrence, invasion of warmer water by cold currents. The other factor, differences in strength of monsoonal circulations, is most pronounced along the borders of areas covered by these seasonal winds. During years of weak monsoon, less territory is covered by the rain-bearing winds and less rain is deposited by them.

Debundscha, Cameroon, has
75 inches
average variability of annual precipitation

The average and relative variability of annual precipitation at 384 places throughout the world were tabulated by E. Biel,[123] and examined statistically by

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121 D. M. Ludlum, *op. cit.*

122 *Ibid.*

123 E. Biel, Die Veränderlichkeit der Jahressumme des Niederschlags auf der Erde [The Variability of the Yearly Amount of Precipitation of the Earth], *Geograph Jaus Oesterreich*, Leipzig, Vols. 14-15, pp. 151-80, 1929.

V. Conrad.[124] Places with greatest average variability (differences between mean value and individual yearly value averaged for a given number of years) were Debundscha, Cameroon, and Cherrapunji, India, with 75.28 and 66.02 inches, respectively. Debundscha is located at 4°01′N, 9°01′E at 30 feet elevation, and has the greatest average annual precipitation in Africa, 405 inches. Cherrapunji has the greatest average annual precipitation in Asia, 450 inches.[125] Because the rainfall amounts at these places are so high, the average differences from year to year can be correspondingly high without being extreme in proportion to the mean. In addition to having a very high average variability of annual precipitation, Cherrapunji may hold the record for the highest actual amount of variability. The difference between the greatest amount of precipitation there during a calendar year, 905.1, and the least amount, 282.6, is over 600 inches.[126]

Themed, Israel, has a
94 percent
relative variability of annual precipitation

Themed is a desert station on the Sinai Peninsula. Its relative variability record is based on the ratio between the mean deviation from the arithmetic mean of annual precipitation for a period of years beginning in 1921 and ending in 1947 and the arithmetic mean for those years.[127] Other places with high values based on this same measure of variability are Walvis Bay at 22°53′S, 14°26′E in South-West Africa with 87 percent,[128] and Malden Island in the Line Islands of the Equatorial Pacific with 71 percent.[129] Walvis Bay, like Themed, is a very dry area and because the rainfall amounts at these places are so low, a small variation in actual amount can become a large percentage of the mean value. Malden Island's average variability of 20.24 inches from its mean annual precipitation of 28.6 inches is thought to be due to displacement of ocean currents.[130]

The relative variability of monthly rainfall can have much higher values. A value of 193 percent for September has been cited at Beersheba, Israel (31°14′N, 34°47′E) where rain fell in only one of 30 Septembers from 1921 through 1950.[131]

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124 V. Conrad, The Variability of Precipitation, *Monthly Weather Rev*, Vol. 69, No. 1, pp. 5-11, Jan 41.

125 U. S. Environmental Science Services Administration, *Worldwide Extremes of Temperature, Precipitation and Pressure Recorded by Continental Area*, *op. cit.*

126 *Ibid.*

127 J. Katsnelson and S. Kotz, On the Upper Limits of Some Measures of Variability, Archiv fur Meteorologie, Geophysik und Bioklimatologie, Ser. B, Vol. 8, No. 1, pp. 103-107, 1957.

128 *Ibid.*

129 E. Biel, *op. cit.*

130 *Ibid.*

131 J. Katsnelson and S. Kotz, *op. cit.*

This almost reaches the theoretical upper limit of 200 percent determined analytically by Schumann and Mostert.[132]

Lhasa, Tibet, had a
108 percent
relative variability
of annual precipitation, 1935 through 1938

Lhasa is located on the Tibetan plateau at 29°40'N, 91°07'E, elevation 12,090 feet. It is in an approximately east-west valley flanked on both sides by mountains of 15,000 to 16,000 feet. Its climate has been described by Gimn-Tze Hsü, who established a meteorological station there in 1934,[133] and also by A. Lu[134] and H. Flohn.[135] Data for 1935 through 1938 from Lu's paper[136] were calculated by Conrad's methods[137] to obtain the average variability of 67.7 inches and a relative variability of 108 percent.

In 1936, the annual precipitation reported for Lhasa, 198.3 inches, was more than 10 times greater than the average amount. However, there is some doubt as to the authenticity of the amount of precipitation recorded for 1936. Flohn considers the value questionable and attributes it to a possible misplacement of a decimal point by a partly educated weather observer.[138] On the basis of Lu's data and data for most of the years from 1941 to 1955, Flohn found no amounts that even approached that of 1936. The highest was 22.9 inches. The frequency of precipitation, as indicated by the number of rainy days during 1936, was not unusual. Furthermore, Gyantse, in the same climatic region as Lhasa at 28°56'N 89°36'E, elevation 10,486 feet, had no similar extreme variation in a 38-year period. In 1936, Gyantse had only 13 inches more than the average precipitation.

However, Hsü was at Lhasa in 1936, presumably as the station observer or supervisor, and he wrote about the unusually heavy rain and its causes[139] and informed Lu[140] of the difference between the rainfall in 1936 and in other years.

132 T. E. W. Schumann and J. S. Mostert, On the Variability and Reliability of Precipitation, *Amer Meteorol Soc Bull*, Vol. 30, No. 110, 1949.

133 Gimn-Tze Hsü, A Note on the Climatic Conditions of Lhasa, *Amer Meteorol Soc Bull*, Vol. 22, No. 2, pp. 68-70, Feb 41.

134 A. Lu, A Brief Survey of the Climate of Lhasa, *Quarterly J Roy Meteorol Soc*, Vol. 65, No. 281, pp. 297-302, Jul 39.

135 H. Flohn, Beitrage zur Klimakunde von Hochasien, [Contributions Towards a Climatology of the Central Asian Plateau]. *Erdkunde*, Vol 12, No. 4, pp. 294-308, Dec 58.

136 A. Lu, *op. cit.*

137 V. Conrad, *op. cit.*

138 H. Flohn, *op. cit.*

139 Gimn-Tze Hsü, *op. cit.*

140 A. Lu, *op. cit.*

Normally, rainfall at Lhasa comes from thundershowers, but in 1936, only 23 percent was of this type and 69 percent was from nighttime rain, possibly caused by interaction between a strong southwest monsoon and cold air masses from the north.[141] In another paper, Lu described a similar extreme variation at Omei Shan, China, to the east of Lhasa, at approximately 29°30'N, 103°30'E, elevation 10,023 feet.[142] The annual mean there is 73 inches, but during the Second Polar Year from August 1932 to August 1933 Omei Shan had 319 inches, " . . . the largest amount ever recorded in China in a 13-month period . . . . "[143] This difference of 246 inches between the annual mean and the August 1932 to August 1933 value is even greater than the difference between Lhasa's annual mean and its 1936 precipitation. Flohn's paper also mentioned Omei Shan, but his figures differ somewhat from Lu's with a 25-inch annual mean and 300 inches in the Second Polar Year, making a difference of 275 inches.[144]

d. Hail.

U.S. largest hailstone
17.5 inches circumference
Coffeyville, Kansas, 3 September 1970

Hailstones are pieces of ice which fall as precipitation either separately as spheres or cones or agglomerated into irregular lumps. They originate in convective clouds of the cumulonimbus type and are usually associated with thunderstorms. The hailstone at Coffeyville, 37°02'N, 95°37'W is the largest officially recorded in the United States. It was irregular in shape and weighed 1.67 pounds.[145] It fell during a severe storm with hundreds of other large stones and was preserved and sent to the National Center for Atmospheric Research where it was photographed. The previous official record for largest hailstone in the United States, which appeared on the earlier *Weather Extremes* maps, was for a hailstone that weighed 1.5 pounds and measured 17 inches in circumference. It was recorded at Potter, Nebraska, on 6 July 1958.

Claims have been made of large hailstones in many places. One hailstone weighing 972 grams (2.14 pounds) was picked up and photographed in Strasbourg, France, near the German border on 11 August 1958, and a heavier one of 1.9 kilograms (4.18 pounds) was collected in Kazakhstan U.S.S.R. in 1959.[146] In a review[147] of a

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141 *Ibid.*

142 A. Lu, Precipitation in Tibet, *Geograph Rev*, Vol. 37, No. 1, pp. 88-93, Jan 47.

143 *Ibid.*

144 H. Flohn, *op. cit.*

145 *Amer Meteorol Soc Bull*, Vol. 52, No. 2, title page, 1971.

146 J. P. Verdon, Extrêmes climatiques mondiales, [World Climatic Extremes], France - Direction de la Météorologie Nationale, Bulletin d'Information, April 1972.

147 K. Bognar, Reminiscences, *Amer Meteorol Soc Bull*, Vol. 52, No. 11, pp. 1102-03, 1971.

Hungarian publication,[148] it is noted that hailstones reported in the publication weighed 3.5 to 4.0 kilograms (8 to 9 pounds) compared to a weight of less than 1 kilogram for the one at Coffeyville. These Hungarian hailstones fell at Söjtör village in Zala country in August 1786, but " . . . probably a few hailstones were clustered together . . . . " [149] Hailstones weighing up to 7.5 pounds have been reported from India and up to 10 pounds from China.[150] Hailstones in these countries are said to have killed people and animals and destroyed villages.[151, 152]

e. **Snow.** There are two main ways of measuring snowfall depth: by direct measurement of fresh snow on open ground with a graduated ruler or scale, and by a snow gage. Precautions need to be taken against drifting or blowing snow, or, if the open ground method is used, against measurement of old snow. When there are strong winds, the snow gage is more accurate. Greatest amounts of snowfall – as of rainfall – occur in areas where there is moist air and a mechanism for lifting it. They tend to occur in the middle latitudes rather than at the very high latitudes where there is less moisture.

North America's greatest 24-hour snowfall
76 inches
Silver Lake, Colorado 14-15 April 1921

Silver Lake is located at approximately 40°N, 105°40'W, at 10,220 feet elevation in the Colorado Rockies. The snowfall there in April 1921 established several records: 75.8 inches in 24 hours, prorated from a measured fall of 87 inches in 27.5 hours, 95 inches in 32.5 hours, 98 inches in 72 hours, and 100 inches in 85 hours.[153] According to Paulhus, the measurement was examined thoroughly before being accepted by the U.S. Weather Bureau.[154] ". . . There was no evidence to indicate that the measurement was any less reliable than that of other heavy snowfalls, and it appears that a snowfall of this magnitude is meteorologically possible . . . ." The maximum amount of snow that can fall in 24 hours has been estimated as approximately 72 inches for snow with a density of 0.10 under normal packing conditions and correspondingly greater for lesser density.[155] The density of the snow at Silver Lake was 0.06.[156] During the storm,

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148 A. Réthly, *Weather Phenomena and Havoc Wrought by Weather between 1700-1800 in Hungary*, Hungarian Academy of Sciences, Budapest, 1970.

149 K. Bognar, *op. cit.*

150 F. H. Ludlam, The Hailstorm, *Weather*, Vol. 16, No. 5, pp. 152-62, 1961.

151 J. H. Field, The Meteorology of India, *J Roy Soc Arts*, Vol. 82, p. 784-806, 1933-34.

152 D. M. Ludlum, *op. cit.*

153 J. L. H. Paulhus, Record Snowfall of April 14-15, 1921 at Silver Lake, Colorado, *Monthly Weather Rev*, Vol. 81, No. 2, pp. 38-40, Feb 53.

154 *Ibid.*

155 C. F. Brooks, On Maximum Snowfalls, *Amer Meteorol Soc Bull*, Vol 19, No. 2, p. 87, Feb, 1938.

156 J. L. H. Paulhus, *op. cit.*

thunder occurred in various parts of the region, indicating widespread convective activity, and the combined convective and orographic influences produced excessive amounts of snow at several places. In addition to the record at Silver Lake, a fall of 62 inches in 22 hours was reported at Fry's Ranch, Colorado; both of these exceeded the previous U.S. record of 60 inches in 24 hours at Giant Forest, California, in January 1933.[157]

Alaska's greatest snowfall in
24 hours, 62 inches, 29 December 1955
one storm, 175 inches, 26-31 December 1955
one season 974 inches, 1952-1953
Thompson Pass

This station is in south-central Alaska, at 61°07'N, 145°44'W, elevation 2,700 ft. It ranks near the top among places holding North American records for the greatest amounts of snowfall in 24 hours, during a single storm and during a season. Besides this, Thompson Pass has extremely frequent occurrences of these intense snowstorms. During the 20 winters from 1951-52 through 1970-71, there were 32 snowfalls of 30 inches or more during a 24-hour observation period reported at this station, and 12 of these snowfalls were at least 40 inches.[158]

Bessans, France, had a snowfall of 68 inches (67.7)
in 19 hours, 5-6 April 1959

Bessans is located at 1710m (5,610 feet) in the French Alps near the Italian border. Very intense snowstorms occur in this area as the result of a South East wind, known locally as "la lombarde." These storms, of which the one at Bessans is a good example, are also very localized; the meteorological and environmental conditions contributing toward them are examined by M. Jail.[159] Parts of Norway also have very high 24-hour snowfalls, as do parts of northwestern Japan and some other world areas. In this connection, it should be mentioned that the predominance of North American records in our listing (see the table, pages 7-15) is due to their availability rather than to greater amounts of snowfall on this continent.

5. **Other Extremes.** Besides temperature and precipitation, several other meteorological and climatic conditions are shown on the maps. For each of these, the most extreme occurrences have their own particular set of causes, limits, and distributions in time and space, and for each there are problems in obtaining accurate measurements.

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157 J. L. H. Paulhus, *op. cit.*

158 *Climatological Data, Monthly, Alaska*, Asheville, N. C., U.S. Weather Bureau, 1951-65, U.S. Environmental Data Services, 1965-71.

159 M. Jail, Remarquable effet de lombarde: les chutes de neige de Paques 1969 en Haute-Maurienne, *Revue de Geographie Alpine*, Grenoble, Vol. 57, No. 3, pp. 613-21, 1969.

In evaluating reliability of the records, all of these factors should be taken into consideration.

a. **Thunderstorms.** A thunderstorm is defined as " . . . in general, a local storm invariably produced by a cumulonimbus cloud, and always accompanied by LIGHTNING and THUNDER, usually with strong gusts of wind, heavy rain, and sometimes HAIL. It is usually of short duration, seldom lasting over two hours for any one storm . . . . "[160] Criteria for recording thunderstorms can vary between storms actually occurring at a station, or merely thunder heard or lightning seen from the station.

Thunderstorms are most prevalent in warm weather and, in some places, during the rainy season. However, although thunderstorms frequently produce heavy rainfall, there are places where seasons of rainfall and thunderstorm maxima do not coincide. In addition, some very rainy places have few thunderstorms, while places with very frequent thunderstorms can have relatively small amounts of rainfall.[161]

Kampala, Uganda averages
242 thunderstorm days per year

Kampala is located to the north of Lake Victoria at 0°20'N, 32°36'E at 4,304 feet. It has the highest number of thunderstorm days of any place listed in the *World Distribution of Thunderstorm Days.*[162] The record for Kampala is based on a period of 10 years, but the particular years are not given. Because diurnal variations of air temperature are very small over Lake Victoria and large over the surrounding area, land and lake breezes develop and conditions become favorable for thunderstorms. " . . . Land-breeze convergence over the Lake during the night releases the latent instability of the moist lower layers of air over the Lake which participate in the land breeze circulation, resulting in the development of cumulonimbus clouds and thunderstorms over the Lake on most nights of the year . . . . "[163] When these storms are close enough for thunder to be heard at Kampala, they are counted as thunderstorms there even though they do not actually reach the town.[164] In addition to these night storms, others develop overland at certain times of the year from afternoon convection at the lake

[160] *Glossary of Environmental Terms (Terrestrial)*, MIL-STD-1165, Washington, D. C., Dept of Defense, 25 Mar 68.

[161] W. H. Portig and J. R. Gerhardt, *Research in Tropical Meteorology*, Second Interim Technical Report, Austin, Texas, Univ of Texas, Electrical Engineering Research Laboratory (Sponsored by U. S. Army Research and Development Laboratory, Fort Monmouth, New Jersey), 1962.

[162] World Meteorological Organization, *World Distribution of Thunderstorm Days* (OMM, No. 21), Geneva, Switzerland, 1953.

[163] E. E. Lumb, Topographic Influences on Thunderstorm Activity Near Lake Victoria, *Weather*, Vol. 25, No. 9, pp. 404-10, 1970.

[164] W. H. Portig, Research Meteorologist, U. S. Army Tropic Test Center, Fort Clayton, Canal Zone, Correspondence dated 23 Nov 70.

breeze front.[165] Thus, the Kampala area is subject to frequent thunderstorm activity, and nearby stations such as Entebbe and Kisumu also average very high numbers of thunderstorm days per year.[166]

Bogor, Indonesia, averaged
322 thunderstorm days per year
1916-1919

Bogor, formerly Buitenzorg, is located on the island of Java at 6°30'S, 106°48'E. The mean annual number of thunderstorm days recorded there changed from 151 in the years 1841-1857 to 322 in 1916-1919; it ranged from 4 to 41 for the years 1953 through 1962.[167] These differences might reflect changes in the criteria for recording thunderstorms. For instance, " . . . during a certain period . . . . " Bogor recorded lightning seen in addition to thunder heard and thunderstorm at the station.[168] Also, the interpretation of 322 in the Bogor record is doubted by W. H. Portig[169] and others who consider that it represents the " . . . mean numbers of occurring thunderstorms and not the mean number of days on which thunder was heard . . . . " According to Portig, the " . . . absolute occurring maximum . . . . " is indicated by statistical curves to be ". . . approximately 250 or 260 thunderstorm days annually, although such a location has not as yet been found . . . . " [170]

b. Air Pressure. The pressure value for a given unit area of surface very nearly represents the actual weight of a vertical column of air of the same unit area extending upward from that surface to the top of the atmosphere. At sea level, this column of air averages about 14.7 pounds (29.92 inches of mercury) per square inch of exposed surface, but the weight varies with latitude and with changes in daily weather. It falls with altitude from an average of 31.3 inches in the earth's deepest depression, 1,300 feet below sea level, to less than half that amount (about 14.9 inches) at 18,000 feet. At the top of the world's highest mountain, 29,028-foot Mt. Everest, it would be about 9 inches.

Air pressure is usually measured by mercurial or aneroid barometers. The former balances pressure of the atmosphere against the weight of a column of mercury. The aneroid or elastic type contains a hollow metal chamber, partly emptied of

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165 F. E. Lamb, *op. cit.*

166 *Ibid.*

167 V. I. Arabadzhi, Klimat i grozy, Climate and Thunderstorms, *Priroda*, No. 2, pp. 65-66, Feb 66. Translated by E. R. Hope as Canada, Defence Research Board, Translation T 456R, Apr 66.

168 W. H. Portig, *op. cit.*

169 W. H. Portig, Thunderstorm Frequency and Amount of Precipitation in the Tropics, Especially in the African and Indian Monsoon Regions, *Archiv fur Meteorologie, Geophysik und Bioklimatologie*, Ser. B, Vol 13, No. 1, pp. 21-35, 1963.

170 *Ibid.*

air and sealed, which expands and contracts as the pressure changes. Mercurial barometers are generally more accurate, but the aneroids are smaller and more portable. Since mercury is affected by temperature and gravity, adjustments must be made in the readings of mercurial barometers to allow for these factors. Also, in order to standardize readings of any kind of barometer when made at different times and places, adjustments are required to compensate for errors in the individual instrument used (index error) and for differences in altitude. For the altitude correction the station pressure readings are usually equated to sea level pressure, and these are the values which are recorded. There are possible sources of error peculiar to each type of barometer, as well as errors that could result from making the various types of adjustments. For example, different values can be obtained when different methods are used for reducing the actual or station pressure to its sea level equivalent.

(1) **High Pressure.** The highest station pressures occur at the lowest elevations; i.e., in depressions below sea level such as Death Valley, California, where the lowest point is -280 feet; the Qattara depression in northwestern Egypt, with a minimum elevation of -436 feet; and the shores of the Dead Sea between Israel and Jordan, at -1,286 feet. In the Dead Sea area, a station pressure of 31.91 inches was reported at Sedom (the biblical Sodom) on 21 February 1961.[171] Another depression, the Turfan in central Asia at approximately 45°N, 90°E, is thought to have station pressures similar to or even higher than those of the Dead Sea area.[172] However, after the adjustment to sea level is made for pressure readings at places below sea level, the values recorded are lower. At or near sea level, high pressures occur along Arctic coasts. Values of 31.37 inches (31.38 sea level equivalent) and of 31.40 inches (31.41 sea level) have been recorded at Clyde in northeastern Canada and at Myggbukta in East Greenland on 18 January 1958 and 15 January 1940, respectively.[173] [174] At stations above sea level the pressure readings are actually lower, but when equated to their sea level equivalents, the values recorded are higher.

World's highest sea level air pressure:
32.01 inches
Agata, U.S.S.R., 31 December 1968

The highest recorded pressures occur in Siberia during winter. Agata is located in this area at 66°53'N, 93°28'E, elevation 855 feet. The high

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171 A. Court, Improbable Pressure Extreme: 1070 mb. *Amer Meteorol Soc Bull*, Vol. 50, No. 4, pp. 248-50, Apr 69.

172 A. Loewe, More on "Improbable Pressure Extreme: 1070 mb." *Amer Meteorol Soc Bull*, Vol. 50, No. 10, pp. 804-806, Oct 69.

173 A. Court, Improbable Pressure Extreme: 1070 mb. *Amer Meteorol Soc Bull*, Vol. 50, No. 4, pp. 248-50, Apr 69.

174 R. Scherhag, *Neue Methoden der Wetteranalyse und Wetterprognose*, [New Methods of Weather Analysis and Weather Forecast]. Berlin, 1948.

pressure record there was the culmination of an intense anticyclone which originated in East Siberia on 22 December and continued until 2 January when it declined somewhat as it moved south and west into European Russia.[175] On 31 December, seven stations in north-central Siberia had air pressures above 31.565 inches (1.070 millibars). The weather was clear and calm with temperatures between -40° and -50°C. Previous world records for high pressure were 31.84 inches at Barnaul, Siberia, in 1900 and 31.75 inches at Irkutsk, Siberia, in 1893.

(2) Low Pressure. The lowest station pressures occur at the highest altitudes; e.g., in the Himalayas of Asia, the Andes in South Ameria, and the Rockies in western North Amerira. Beginning at about 4,000 feet, the average station pressures are lower than the most extreme low pressures that occur at sea level. At the approximate upper limit of weather stations, 15,000 feet, standard pressure is 16.90 inches and the extreme lowest is estimated at about 14.76 inches.[176] At sea level, the lowest pressures and most rapid falls in pressure occur during hurricanes and tornadoes. "... Accurate pressure measurements by a recorder directly in the center of a tornado have never been made ...."[177] but various estimates are available. According to one estimate, the drop in pressure can be as great as one fifth of an atmosphere, i.e., about 6 inches.[178] Other estimates are for "... a reduction of no more than one fourth of the pre-existing pressure ..." which could occur "... within 15 seconds ..."[179] and a drop of 1.5 pounds per square inch (3 inches) and a time change of 0.5 psi (1 inch) per second in pressure of tornadoes with 200-mile per hour winds.[180]

World's lowest air pressure at sea level
(excluding tornadoes)
25.90 inches
estimated by aerial reconnaissance in eye of Typhoon Ida at
19°N, 135°E, 24 September 1958

Reliability of the estimated record has been evaluated by Jordan.[181] It was based on a dropsonde observation made from the 700-millibar level by a U. S. Air Force reconnaissance aircraft of the 54th Weather Reconnaissance Squadron.

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175 B. D. Giles, Extremely High Atmospheric Pressures, *Weather*, Vol. 25, No. 1, p. 19-24, 1970.

176 A. Court and H. A. Salmela, Improbable Weather Extremes and Measurement Needs, *Amer Meteorol Soc Bull*, Vol. 44, No. 9, pp. 571-75, Sep 63.

177 D. M. Ludlum, *op. cit.*

178 "Tornadoes," in: *Encyclopedia of Atmospheric Science and Astrogeology*, Reinhold, N. Y., 1967.

179 A. Court and H. A. Salmela, *op. cit.*

180 T. T. Fujita, *Estimate of Maximum Wind Speeds of Tornadoes in Three Northwestern States*, Chicago Univ., Ill. Dept. of the Geophysical Sciences, Research Paper 92, NOAA-71060308, Dec 70.

181 C. L. Jordan, A Reported Sea-Level Pressure of 877 mb, *Monthly Weather Review*, Vol. 87, No. 9, pp. 365-66, Sep 59.

about 600 miles northwest of Guam. In the observation, the 700-millibar height was determined from the pressure and radio altimeters aboard the aircraft, and the 850-millibar height and sea level pressure were computed from temperature and humidity data measured by the aircraft instruments at flight level and by the dropsonde instrument at levels below the aircraft. According to Jordan, the sounding was found to be hydrostatically consistent and the vertical temperature distribution was realistic.[182] A source of major error in this type of measurement would be in the aircraft altimetry, but on reconnaissance aircraft, calibration checks are a routine part of each flight. Dropsonde observations from two other aircraft, made about 8 hours earlier and 23 hours later, respectively, both reported sea level pressures lower than the previously accepted lowest pressure of 26.185 inches from the SS *Sapoerea*. Lower values than the *Sapoerea's* were also reported in 1953 during Typhoon Nina, with dropsonde sea level pressures of 886 millibars (26.17 inches) and 883 millibars (26.04 inches).[183] However, the record taken on the *Sapoerea*, 460 miles east of Luzon, Philippine Islands, on 18 August 1927 was an actual measurement rather than an estimate, and it remains the lowest measured pressure at sea level.[184]

c. **Solar Radiation.** Measurements of the flux of solar radiation penetrating to the lower layers of the atmosphere can be subdivided into several main classes. Values considered here are for global solar radiation received on a horizontal surface. ". . . This includes both radiation received direct from the solid angle of the sun's disc and also radiation that has been scattered or diffusely reflected in traversing the atmosphere . . . ."[185] Such measurements are usually made with pyranometers, and, as in all radiation measurements, considerable care and attention to detail is required to insure accuracy. Several points to be evaluated in estimating accuracy of radiation measurements are listed in the WMO Guide.[186]

South Pole has
955 Langleys
average daily insolation in December

The world's highest daily amounts of solar radiation are received on the Antarctic Plateau during summer when there are 24 hours of continuous daylight.[187] The North Polar area also has continuous daylight during its summer, but at that time of the year the earth is about 3 million miles further from the sun. Consequently,

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182 *Ibid.*

183 *Ibid.*

184 R. J. Schmidli, *op. cit.*

185 World Meteorological Organization, *op. cit.*

186 *Ibid.*

187 K. J. Hanson, Some Aspects of the Thermal Energy Exchange on the South Polar Snow Field and Arctic Ice Pack, *Monthly Weather Review*, Vol. 89, No. 5, pp. 173-77, May 61.

about 7 percent more solar radiation impinges on the top of the Antarctic's atmosphere than on the Arctic's during midsummer.[188]

The South Pole record was obtained by averaging daily values of hemispheric global solar radiation, which were available from Amundsen-Scott Station for the Decembers of 1958 through 1965.[189] The resultant value was 954.6 langleys. Amundsen-Scott is located at an elevation of 9,186 feet, at 90°S. However, the average daily insolation could be greater at other stations in the Antarctic.[190]

Malange, Angola had a solar radiation of
113 langleys in one hour
7 November 1961

Malange is located in western Africa at 9°33'S, 16°22'E, altitude 3,710 feet. A very high reading of 112 langleys in 1 hour was also obtained at Windhoek, South West Africa (22°34'S, 17°16'E, altitude 5,640 feet) on 20 December 1956.[191] High hourly values of solar radiation can be expected at relatively low latitudes during the hours of the day and times of the year when the sun is strongest and when cloud cover is absent and the air is as clear as possible from dust and other impurities. Other things being equal, they would tend to occur at the higher elevations.

d. **Wind Speed.** Of all the elements, wind is most variable. To compare wind speeds reported from various places and times, information should be known about the height and exposure of the measuring instrument (anemometer), the type of instrument and record, and the time interval covered by the measurement. Wind speed is usually measured by either rotating or pressure anemometers. In the former type, wind passage is measured by the rate of motion imparted to a freely rotating mechanism, and a timing mechanism is usually combined with the anemometer to indicate the rate of passage. Pressure anemometers measure the instantaneous speeds (actually averages for about 1 second) by means of pressure effects; i.e., force applied to a surface or surfaces. The time intervals of wind observations differ between countries and even between stations. In the U.S., the extreme values tabulated are: the greatest average speed over a 5-minute interval, *maximum speed;* the speed of the fastest mile of wind from the record of rotating anemometers, *extreme speed;* and the highest reading of the instantaneous recording anemometers, *strongest gust*.[192] In addition, extreme average

188 *Ibid.*

189 U. S. Environmental Science Services Administration, Environmental Data Service, Climatological Data for Antarctic Stations, Nos. 1 and 9, Washington, D. C., GPO, 1962 and 1968.

190 Personal communication, M. Kuhn, University of Innsbruck, Innsbruck, Austria.

191 *Quart Radiation Bull*, Union of South Africa, Vol. 3, No. 1/2, p. 17, 1957.

192 A. Court, Wind Extremes as Design Factors, *J Franklin Inst*, Vol. 256, pp. 39-56, Jul 53.

values are obtained from records of the total wind passage in each hour from recording rotation anemometers at the principal weather stations.[193]

Winds are strongest at the times and places of maximum temperature and pressure gradients. They increase with altitude and during thunderstorms, hurricanes, and tornadoes. Gusts are sudden brief increases in the speed of wind, usually less than 20 seconds in duration,[194] and are known to exceed 200 miles per hour in hurricanes and tornadoes.[195] A tornado is defined as " . . . a slightly funnel-shaped, upward-spiraling wind column of destructive velocity . . . . " [196] Because wind measuring instruments are unable to withstand the full impact of a tornado, estimates of the wind speed are made on the basis of various criteria such as the amount of force that would be required to cause the resultant damage. According to Ludlum, the maximum winds in a tornado probably range between 150 and 225 miles per hour.[197] Fujita gives a similar range of values, 175 to 225 miles per hour based on his investigation of tornadoes occurring in the states of Washington, Oregon, and Idaho during the years 1950-1969.[198]

World's highest surface wind
(excluding tornadoes)
231 miles per hour, peak gust, and
188 miles per hour, 5-minute wind speed, on
12 April 1934 and

U. S. highest annual mean wind speed
35 miles per hour (35.4)
Mt. Washington, New Hampshire

Winds are stronger at the summit of this 6,288-foot mountain, at 44° 16'N, 71°18'W, than they are at the same elevation in the free air some distance away. " . . . This is probably due to 'uplift' over the slope or to the Bernoulli effect introduced by the surrounding mountains. Windspeeds of 100 mph are not uncommon . . . . " [199] The speed of the peak gust was measured by a heated rotation anemometer, but, in such strong winds, no apparatus can record the airflow except approximately, and actual

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[193] *Ibid.*

[194] R. E. Huschke, ed., *Glossary of Meteorology*, Boston, Mass., Am Meteorol Soc, 1959.

[195] C. F. Riley, Jr. and P. F. Walker, *Atmospheric Pressure Criteria for Aircraft and Airborne Equipment*, WADC Tech Note 55-98, Chapter II, "Wind," Wright-Patterson Air Force Base, Ohio, 1955.

[196] *Ibid.*

[197] D. M. Ludlum, *op. cit.*

[198] T. T. Fujita, *op. cit.*

[199] U. S. Environmental Science Services Administration, Environmental Data Service, *Local Climatological Data: annual summary with comparative data, 1967, Mount Washington Observatory, Gorham, New Hampshire*, Washington, D. C., U. S. Govt. Print. Off., 1968.

velocity may be in error by 10 to 40 miles per hour.[200] [201] The 231-mile-per-hour value is documented in the official records.[202] A value of 225 miles per hour, after anemometer calibration, is given in some sources[203] and was cited in previous editions of the Weather Extremes map. Direction of the wind during the gust was from the southeast, the direction from which the most severe storms in the Mt. Washington area usually come. Its force, due to the reduced air density on the mountain top, was equal to that of about a 180-mile-per-hour wind at sea level.[204]

The highest 5-minute maximum speed at Mt. Washington is 18[illegible] miles per hour, recorded on the same day as the peak gust.[205] The second highest gust that occurred on Mt. Washington is apparently the 189 miles per hour estimated during the hurricane of 21 September 1938.[206] The strongest gust speed that was actually measured during the 1938 hurricane was 183 miles per hour (corrected) at the Blue Hill Observatory in Milton, Massachusetts;[207] 5-minute speeds at the Observatory were up to 121 miles per hour.[208] The annual mean wind speed recorded on Mt. Washington varies with the period of observation; values of 36.9, 37.2, and 34.4 were also found.[209] [210] [211]

Thule, Greenland, had a
207 miles per hour peak gust
8 March 1972

This peak wind speed of 180 knots (207 miles per hour) was recorded at 2155 hours (9:55 p.m.) at an off-base survival shelter at 76°31′20″N, 68°19′00″W, elevation 990 feet.[212] It was observed by two site dispatchers on an anemometer capable of

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200 C. F. Brooks, The Worst Weather in the World, *Appalachia*, pp. 194-202, Dec 40.

201 Note on the Precipitation, Snowfall and Wind Records, *Mount Washington Observatory News Bull*, No. 22, pp. 23-24, Jun 53.

202 U. S. Environmental Science Services Administration, Environmental Data Service, *Local Climatological Data: annual summary with comparative data*, 1967, Mount Washington Observatory, Gorham, New Hampshire, Washington, D. C., U. S. Govt. Print. Off., 1968.

203 A. Court, Wind Extremes as Design Factors, *J. Franklin Inst*, Vol. 256, pp. 39-56, Jul 53.

204 *Ibid.*

205 R. J. Schmidli, *op. cit.*

206 C. F. Brooks, The Worst Weather in the World, *Appalachia*, pp. 194-202, Dec 40.

207 A. Court, Wind Extremes as Design Factors, *J Franklin Inst*, Vol. 256, pp. 39-56, Jul 53.

208 U. S. National Oceanic and Atmospheric Administration, Environmental Data Service, *Local Climatological Data: annual summary with comparative data*, 1970, Blue Hill Observatory, Milton, Massachusetts, Washington, D. C., GPO, 1971.

209 L. H. Seamon and G. S. Bartlett, *op. cit.*

210 Note on the Precipitation, Snowfall and Wind Records, *op. cit.*

211 F. Landsberg, Uber die Verteilung der Windgeschwindigkeit auf der Erde, On the Distribution of Wind Velocity Over the Earth, *Arch Meteorol Geophys Bioklimatol*, Series B, Vol. 2, No. 5, p. 136, 1951.

212 J. R. Stansfield, The Severe Arctic Storm of 8-9 March 1972 at Thule Air Force Base, Greenland, *Weatherwise*, Vol. 25, No. 5, pp. 228-33, 1972.

registering winds of up to 276 miles per hour. It occurred at a considerably lower elevation than the peak gust on Mt. Washington and, consequently, could have exceeded it in force. The gust was observed during a severe Arctic storm in which the site experienced winds of 146 miles per hour or greater for 4 hours. Similar, though somewhat lesser, speeds were observed throughout the area. The U. S. Air Base at Thule had a speed of 110 miles per hour. High winds are common in this northwest Greenland area due to intense winter storms and local topographic conditions. Winds blowing down from the dome-shaped Greenland icecap are accelerated by gravity and by compression and funneling as a result of the local orientation of mountains and valleys.

Miyakojima Island, Ryukyu Islands had a
190 mile-per-hour peak gust and a
maximum wind speed of 136 miles per hour
5 September 1966

These wind speeds were observed at the Miyakojima Weather Station and have been officially reported by the Ryukyu Meteorological Agency. They occurred during a typhoon whose maximum wind zone passed over the island. The peak gust of 85.3 meters per second (190 miles per hour) was recorded at 0631 hours (6:31 a.m.) and the maximum wind of 60.8 meters per second (136 miles per hour) at 0731 hours (7:31 a.m.).[213] The direction of both was Northeast. Miyakojima is a small, flat island located at about 24°47'N, 125°17'E. Since the record there occurred at sea level, there would have been no reduction in the force of the wind. Typhoons of similar severity occur about once or twice a year in the northwest Pacific area.[214]

Port Martin, Antarctica, had
a 24-hour mean wind speed of 108 miles per hour
21-22 March 1951
a mean monthly wind speed of 65 miles per hour
March 1951

These wind speeds were recorded at a station maintained by the Expéditions Polaires Françaises at 66°49'S 141°24'E on the coast of Adélie Land from February 1950 to January 1952.[215] The wind measuring installations did not fully comply with international standards, being somewhat sheltered by snowdrifts, or the values would have been slightly higher.[216] Winds of hurricane force (74 miles per hour or greater) were recorded at the station on 10 consecutive days in March 1951 and on 122

[213] Y. Mitsuta and S. Yoshizumi, Characteristics of the Second Miyakojima Typhoon, *Kyoto, Japan, Univ. Disaster Prevention Research Bulletin*, Vol. 18, pt. 1, No. 131, pp. 15-31, 1968.

[214] *Ibid.*

[215] F. Loewe, The Land of Storm, *Weather*, Vol. 27, No. 3, pp. 110-121, 1972.

[216] *Ibid.*

days during calendar year 1951. The hurricane force winds are extremely steady both in their direction, south-southeast, and in their strength, which varies very little and appears lacking in normal gustiness. However, they can within a minute drop from full hurricane strength to near-calm and just as suddenly return. Extreme winds were also reported by Mawson's expedition at nearby Cape Denison, 67°1'S, 142°41'E in 1912 and 1913.[217] Various explanations of the causes of strong winds in this part of Antarctica have been advanced;[218] but as yet the reasons for them are not definitely established.[219]

e. **Dewpoint (Humidity).** Dewpoint is " . . . the temperature to which a given parcel of air must be cooled at constant pressure and constant watervapor content in order for saturation to occur . . . ."[220] This temperature is measured by instruments in which a mirror or other element is cooled to the saturation point. High dewpoints indicate high humidity, and low dewpoints indicate low humidity. As far as could be ascertained, there are no accepted extreme records of high or low dewpoints. The high values cannot be higher than the temperature of the body of water from which the vapor originates. They occur in proximity to water bodies with high surface temperatures such as parts of the Gulf of California, the Red Sea, the Persian Gulf, and possibly in some tropical swamplands.

Assab, Ethiopia, has
84°F
Average afternoon dewpoint in June

The dewpoint value for Assab was taken from a footnote in a report by A. Dodd:[221] " . . . Recently available data furnished by the National Weather Records Center indicate that very high dew points occur also in the Red Sea littoral. Assab and nearby Ras Andaliglie on the Red Sea coast of Eritrea (Ethiopia) had *average* afternoon dew points higher than 84°F . . . ."

f. **Fog.**

U. S. West Coast highest average fog frequency
2552 hours per hear
Cape Disappointment, Washington

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217 *Ibid.*

218 K. B. Mather and G. S. Miller, The problem of the Katabatic Winds on the Coast of Terre Adélie, *Polar Record*, Vol. 13, pp. 125-32, 1967.

219 F. Loewe, *op. cit.*

220 R. E. Huschke, ed., *op. cit.*

221 A. A. Dodd, *Areal and Temporal Occurrence of High Dew Points and Associated Temperatures*, Tech Rpt ES-49, U. S. Army Natick Laboratories, Natick, Mass., Aug 69.

U. S. East Coast highest average fog frequency
1580 hours per year
Moose Peak Lighthouse, Mistake Island,
Maine

Fog is a cloud at the surface of the earth, consisting of a multitude of minute water droplets suspended in the atmosphere; according to international definition, it reduces horizontal visibility below 1 kilometer, or 0.62 miles.[222] It can occur, if there are sufficient condensation nuclei present, whenever the air is cooled to its dewpoint or the dewpoint is raised by the addition of moisture to the air. Fog occurs most often on mountains where the surface of the earth is high enough to be in the clouds and on coasts where land and water temperatures differ and moisture is present. The records for Cape Disappointment and Moose Peak Lighthouse were obtained from M. A. Arkin of the U. S. Environmental Data Service. They are based on fog signal operation and on low visibility operation of radio beacons at light stations, lightships, and other Coast Guard units during a period of 10 years or longer. Also, for a 4-year period at Willapa, Washington, the average was 3,863 hours per year, and for one of those years the total was 7,613 hours. Mountain stations with very frequent occurrences of fog are Mt. Washington, New Hampshire, averaging 308 days a year on which there is some fog, and Stampede Pass, Washington, averaging 252 days.[223]

III. CONCLUSIONS

6. Conclusions. From the foregoing examples and discussions, several points seem to stand out:

a. For each meteorological and climatological element there are certain conditions or combinations of conditions that favor extreme values and are most likely to occur within particular geographical areas or seasons of the year; also, there are upper and lower limits of the values that can possibly occur. The records shown on the world and North American maps appear to be within the limits of possibility and to have occurred in places and at times in which the necessary conditions could be expected. However, occurrences of equal or greater extremity could have happened at other places in the same areas or at other times in the same places without being recorded or without being publicized. There is no routine exchange of such information between different countries.

b. For each meteorological and climatological element, there are factors of site, instrumentation, and observational procedure which can affect the measured values.

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222 D. M. Ludlum, *op. cit.*
223 *Ibid.*

To insure uniformity of measurements, certain standardized equipment and procedures are recommended by the World Meteorological Organization. However, standardized equipment can malfunction and errors can be made in observation and recording, even under standard procedures. Further, improvements in the reliability of measurements continue to be made as knowledge of both technology and the physical environment increases. Some of the earlier records might have different values if measured with the newest instruments and procedures; even now, extremes are sometimes not measured exactly, or at all, because they exceed the scale of standard meteorological instruments or their rate of response.[224] For these reasons, it is not to be assumed that any one of the values shown on the maps in this report is correct to the tenth of a decimal place; but those for which a claim of record extreme is made were obtained under conditions that were acceptable to the Environmental Data Service.

c. Considerable research remains to be done both on the general subject of extreme weather and climate and on the records of individual extremes. There is more to be known about the causes of extreme conditions as well as their absolute limits, frequencies, and distributions in time and place. Further search would yield additional records of extremes which are not included on the present maps.

[224] A. Court and H. A. Salmela, *op. cit.*